Reference No. 68-32

SUMMARY OF INVESTIGATIONS CONDUCTED IN 1967

WOODS HOLE OCEANOGRAPHIC INSTITUTION
Woods Hole, Massachusetts

APPROVED FOR DISTRIBUTION Paul M. Fye

Paul M. Fye, Director

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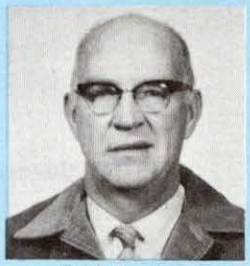

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Foreward

This collection of brief "summaries of investigations" has been prepared by the members of the research staff of the Woods Hole Oceanographic Institution and this volume is a continuation of our early traditions. For the first decade or so reports of progress by individual investigators were included as an appendix to each annual report. There were only fourteen such summaries occupying less than seven pages in the 1931 Annual Report; there were but thirteen persons on the research staff at that time.

With the expansion of the Institution during the World War II years it became impractical to include a comprehensive report of progress for each investigator, but the Annual Reports did continue to describe very briefly the work being done by each. With the continued expansion of the Institution the printed annual report has become more and more impersonal and the lack of a comprehensive summary of current investigations has been apparent to all. The *Collected Reprints* of the Institution have continued to provide a record of the scientific results obtained by our staff members, but publication delays make these at least a year out-of-date before they appear.

This report is the sixth in the series of Summaries of Investigations. They are similar in style to the reports of progress included as appendices to earlier Annual Reports and a limited number of copies is available. This collection of summaries is intended not only to supplement the limited information about the scientific investigations included in the Annual Report for 1967, but also to let our friends and associates know what each individual staff member is currently studying.

These summaries have been reviewed by the department chairmen but typed, insofar as possible, without editorial change, adhering strictly to the original manuscript in most cases.

Acknowledgment of Financial Support

A very large part of the support of our research programs came from the agencies and departments of the Federal Government listed below. We wish to express our thanks to these organizations as a whole and to the executives and administrators in them who have been so helpful to us during the past year.

Acknowledgment of Support

Atomic Energy Commission

Coast and Geodetic Survey

U. S. Coast Guard

Office of Naval Research

Fish and Wildlife Service, Bureau of Commerical Fisheries

U. S. Geological Survey

National Science Foundation

Naval Ship Systems Command

Naval Air Systems Command

National Institutes of Health

National Aeronautics and Space Administration

The support for our research programs provided by private foundations and organizations, individuals and the Associates of the Woods Hole Oceanographic Institution is also very much appreciated, for it enabled us to initiate projects for research or education which could not be funded through Federal agencies.

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DEPARTMENT OF BIOLOGY

John H. Ryther, Department Chairman
David W. Menzel, Assistant Department Chairman

BIOLOGY

MESOPELAGIC FISHES

Richard H. Backus, James E. Craddock, Richard L. Haedrich
Martha Howbert, Giles W. Mead, Jane Peterson
David L. Shores, Asa S. Wing, and Wayne Witzell

Our long-range goal is to understand the geographic distribution of mesopelagic fishes in the North Atlantic Ocean. To that end we collected new material at sea in 1967 and continued the study of earlier collections. Some attention was also given to the improvement of collecting devices and to the storage and analysis of data using the Institution's computer facility.

Thirty-one midwater and 61 neuston collections were made on *Atlantis II* Cruise 31 between Recife and Buenos Aires during February and March. These were our first South Atlantic collections and were made principally to elucidate a problem in the distribution of fishes in the equatorial North Atlantic. Twenty-five midwater and 17 neuston collections were made on *Chain* Cruise 72 between Woods Hole and the Sargasso Sea. These supplement earlier collections and were made for studying Slope Water-Gulf Stream-Sargasso Sea faunal changes. Mr. Witzell made 20 neuston collections on *Chain* Cruise 75 between Barbados and the Mid-Atlantic Ridge during October-December. All of these sets of collections have been given only preliminary processing.

Sorting and identification of the fishes collected on *Atlantis II* Cruise 13 (Woods Hole to Azores and return, September-October 1964) and on *Chain* Cruise 49 (Barbados to Woods Hole, June 1965) were completed. The *Atlantis II* Cruise 13 material comprises about 88,000 specimens of 213 species, the *Chain* Cruise 49 material about 5000 specimens of 129 species. About one half of the material from 68 midwater collections made on *Chain* Cruise 60 in the Caribbean Sea and Gulf of Mexico during May and June of 1966 has been identified. Miss Howbert has made illustrations of about 100 species collected during this cruise.

Study of the *Chain* Cruise 49 material shows that the so-called "thermal front region" in the western Sargasso Sea near 29°N (Voorhis and Hersey 1964) is significant as a faunal boundary. Our data plus gleanings from the biological literature of this area show that the thermal front divides the western Sargasso Sea into two very different areas. Fish catches north of the front are relatively large and diverse. Catches to the south are smaller and less diverse. Furthermore, there are changes at the front in species composition of the fish catches. These results fit with earlier measurements of productivity in the two areas (Ryther and Menzel 1960) and with observations of the planktonic flora (Hulburt 1966) as well as with the seasonal patterns of the density-depth regime. A manuscript discussing these things was well advanced at the close of the year.

Craddock and Mead finished the study of 42 midwater collections made on *Anton Bruun* Cruise 13 in the Peru Current system off central Chile during January and February 1966. This material, which has been completely sorted and identified, comprises 16,469 specimens of 133 species. While the fauna of the southern Peru Current is dominated by subantarctic species, nearly half of the species collected occur also in the North Atlantic. A manuscript on the *Bruun* Cruise 13 fishes was virtually complete by the year's end.

Haedrich, in continuing his systematic studies of stromateoid fishes, described a new species of *Psenopsis* from the eastern Indian Ocean and *Amarsipus carlsbergi*, the type of a new family, from the equatorial Pacific and Indian oceans. Both studies made use of material collected during the International Indian Ocean Expedition. These studies, but especially others still in progress, attempt to understand the factors responsible for the isolation and speciation of fishes on the high seas.

Using neuston net collections made on *Atlantis II* Cruise 31, Martin R. Bartlett* and Haedrich reported upon the distribution of larval blue marlin, *Makaira nigricans*, off the coast of eastern South America. The young stages of this species had been little collected previously.

Haedrich and Craddock completed a manuscript on the rare mesopelagic fish *Winteria telescopa*. Eighteen new records were added to the five previously known. A comparison of these shows that all specimens belong to a single circumgloba species, a solitary fish living between depths of 500 to 700 meters in the transitional areas between water masses.

* Present address: Bureau of Commercial Fisheries, Pascagoula, Miss. 39567

Backus has been collaborating in a small way with Prof. Vadim D. Vladykov, University of Ottawa, in studying our rich collections of leptocephali of the European and American eels (genus *Anguilla*). These studies suggest that the traditional ideas about the oceanic phases of the life histories of these species will be altered. Because of the special nature of the life histories of these fishes, the study of this material may make a useful contribution to oceanic zoogeography.

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OBSERVATIONS OF SOUND-SCATTERERS FROM DSRV *ALVIN*

Richard H. Backus, James E. Craddock, Richard L. Haedrich
Giles W. Mead, David L. Shores, John M. Teal and Asa S. Wing

Between 3-6 October 1967 we were able to answer a question of a dozen years' standing: what causes the peculiar sound-scattering layer found in the Slope Water and known as "Alexander's Acres"? The following abstract is taken from a manuscript submitted for publication:

"A peculiar sound-scattering layer apparently restricted to the Slope Water region of the western North Atlantic has been identified from the DSRV *Alvin* with the myctophid fish *Ceratoscopelus maderensis*. Unlike ordinary oceanic deep scattering layers, this one is composed of discrete hyperbolic echo-sequences. By diving to layer depth and using *Alvin's* sonar, the sound scatterers were closed and visually identified. The number of echo-sequences per unit volume of water observed with the surface echo-sounder checked roughly with the number of sonar targets seen from the submarine. All sonar targets closed with the submarine proved to be *Ceratoscopelus maderensis*. Why sound-scattering layers of this sort are not more widely observed in the deep ocean is not known."

BIOLUMINESCENCE

Richard H. Backus and Asa S. Wing

In order to learn something of the seasonal rhythms of micro-bioluminescence, we have continued a program of continuous observations in Eel Pond channel at Woods Hole. Hourly flash counts are tallied and solar radiation, water temperature, and rainfall are also recorded. Then data are put on paper tape by a Frieden punch so as to prepare them for computer analysis. During 1967 we gathered data, but made no analyses.

MIDWATER SOUND-SCATTERING INTEGRATOR

Richard H. Backus and Asa S. Wing

During 1967, we continued to develop and began to use a device for studying the geographic variation in midwater sound-scattering at 12 kcps. This device, which integrates midwater reverberation in the upper 400

fathoms, operates as an attachment to echo-sounder systems such as the PGR or PDR. As a result of sea trials during 1966, the apparatus was largely rebuilt during 1967. It was used in 1967 on *Chain* Cruise 72 and on *Gosnold* Cruise 106. Further modifications were made as a result. The system can analyze directly the output of the echo-sounder or can process, at sea or ashore, suitably made tape-recordings. Analyses of such tape-recordings was in progress as the year closed.

THE AVOIDANCE OF SAMPLING APPARATUS BY ZOOPLANKTON

Edward R. Baylor

Fleminger and Clutter (1965) have shown that zooplankton in tanks avoid sampling apparatus. We have asked whether zooplankters in the ocean avoid sampling apparatus and, if so, which sense modalities detect the approaching apparatus.

High speed samplers similar to Gulf III were employed. A high frequency sonar beam projected forward through the mouth of the sampler. Animals within the sonar sound cone could be counted just as they entered the mouth of the sampler or at any given distance less than 2 meters ahead of the sampler. Thus, three sets of data were obtained for comparison: the number of organisms captured in the net, the number of organisms counted entering the net aperture, and the number of organisms counted two meters ahead of the net. The agreement between the number of organisms captured and the number entering the mouth of the net was within 90 percent. Most of the remaining 10% could be accounted for by non-living particles which were not counted with the captured organisms.

At 2 knots towing speed, approximately 5 times as many organisms avoided the net as were captured by it. At 4 knots, approximately 3 organisms escaped for each organism caught. At higher towing speeds the ship's generator created a high level of radio frequency interference that obscured the data.

Differences between night and day data suggest that vision is the primary sense modality involved in avoidance responses.

Using night data and comparing zooplankton counts from the mouth of the net with those 15 cm ahead of the net and others 30 cm ahead of the net, we tentatively conclude that some sort of velocity gradient exists at about 10-15 cm ahead of the net that permits chaetognaths to dodge sampling apparatus towed at 150 cm/sec.

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ANIMAL ACOUSTICS

Edward R. Baylor

In an amusing set of experiments aided by Mr. William Watkins and Miss Anne Bowen on the acoustics of animal sound production, we were able to conclude that the vocal sac of frogs and toads functions as a sound radiator instead of as a resonator. Thus the vocal sac imposes no qualitative changes upon the emitted frequency spectrum but serves merely to couple the internally produced sound to the atmosphere. Our findings and those of Dr. Wm. Martin of the University of Texas completely reverse the traditionally held but untested opinions of the functions of the vocal sac. His observations and ours on the number of nodes visible in vibrating vocal cords account for the detectable harmonics and remove the necessity for involving the vocal sac as a harmonic resonator.

PHYSIOLOGY AND BIOCHEMISTRY

Francis G. Carey, John M. Teal and Sonja Hicks

Tuna Fish Thermoregulation

During the past year we have been able to demonstrate that blue-fin tuna (*Thunnus thynnus*) regulate their body temperature to a fairly constant value over a wide range of environmental temperatures. The evidence

for this was obtained by collecting extensive records of the temperatures of tuna from areas with different prevailing water temperatures. During expeditions to Bimini in the Bahamas, Provincetown, Massachusetts, St. Margaret Bay, Nova Scotia, and Conception Bay, Newfoundland, we obtained the temperatures of 150 tuna in waters ranging from 7°C to 29°C. As shown in Fig. 1, the fish varied by only six degrees over this range. This result adds the bluefin to the birds and mammals as a new class of homeotherms. The ability to thermoregulate explains how the tuna can tolerate the great variations in water temperature which they meet during their yearly migrations from the tropics to the arctic. The mako shark (*Isurus oxyrinchus*), is also warm bodied (Fig. 2). Preliminary results indicate that this fish is also able to regulate its temperature, but over a much smaller range than the bluefin. We hope in the future to discover the mechanism through which these fish regulate their temperatures.

Diving in Marine Iguanas

During an expedition to the Galapagos Island we had an opportunity to study diving in marine iguanas (*Ambylrhynchus cristatus*). These large sea lizards typically feed under water and make dives of many minutes duration. They also exhibit intermittent breathing in air, sometimes holding their breath for five minutes or more. We investigated changes in the oxygen and carbon dioxide in the lungs of restrained iguanas both in air and under water. The heart beat rate was also measured and showed a decrease with decreasing oxygen content in the lungs either in air or in water. The oxygen concentration in the lungs decreased rapidly to about 5% of an atmosphere, whereupon the animals in air breathed. Animals held underwater continued to use oxygen when it fell below 5% of an atmosphere, but at a much lower rate and the oxygen did not fall below 2.5% even in dives lasting for one to two hours. Carbon dioxide concentration in the lungs continued to increase linearly throughout the dive. The slowness of oxygen utilization below a concentration of about 5% may indicate that oxygen uptake below this level is limited by the oxygen affinity of the blood.

Crustacean Cuticles

With Drs. Degens and Spencer of the Chemistry Department, the cuticles of portunid crabs were analyzed for their amino acid, amino sugar and calcium composition. Regions in the cuticle show a wide range of flexibility from the very hard and rigid chela to the flexible swimming legs. The calcium content was strongly associated with hardness as were certain amino acids; notably, lysine, proline, histidine and methionine as well as the ratio of amino sugars to total protein. Another group of amino acids, tyrosine, serine, phenylalanine, glycine and aspartate were strongly associated with the degree of flexibility and the ratio of the thickness of tanned to calcified layers in the cuticle. These results are similar to some of the relationships found in mollusc shells.

Glucose in Sea Water

A standard enzymatic assay for glucose using hexokinase and glucose-6-phosphate was modified by coupling it to the reduction of the dye, resazurin, to the highly fluorescent product resarufin (Guilbault and Kramer, 1964). This procedure as modified for use in sea water by Dr. Hicks and Dr. Carey is suitable for measuring free glucose in the sea down to concentrations of 3×10^{-8} M. In cooperation with Mr. Vaccaro and Dr. Jannasch, Dr. Hicks measured free glucose across the Atlantic Ocean during Cruise 31 of the *Atlantis II*. A wide range of glucose concentrations were found, from below 3×10^{-8} M to 10^{-6}M.

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SPECTRAL CHANGES IN LIGHT SCATTERED BY THE SEA AND THEIR SIGNIFICANCE

George L. Clarke

Our basic investigation of the role of light in the sea was continued and extended during the year. Since light penetrating into the water provides energy for the photosynthesis of plants and stimuli for the photic reactions of animals, determinations of the availability and characteristics of light are essential for an understanding

of the production and regulation of life in the sea. The attenuation, scatter pattern, and spectral distribution of underwater light are affected by the water itself and are further modified by dissolved and particulate matter (living or non-living) present. The amount and kind of these "contaminating" materials change from time to time and from place to place, sometimes dramatically. Optical properties may thus be used to delineate water masses and to provide information as to the type and abundance of organisms and/or their by-products present.

In collaboration with G.C. Ewing and A.C. Conrod, measurements were made of the changes in the intensity and spectral distribution of daylight (sunlight plus skylight) at a series of depths at locations off Woods Hole and off Boston using a radiometer in a water-tight and pressure-resistant case. The energy was recorded on a Sanborn strip chart recorder for each of 25 narrow bands between wavelengths of 360 and 650 mμ. By placing the instrument first in the upright position and then in the inverted position, records were made of the downwelling and upwelling radiation, respectively, for each series of depths at each location.

Radiation which had entered the sea and had been scattered out again through the surface was measured by operating radiometers in the inverted position over the water (1) suspended from the boom of the research vessel and (2) mounted in the research airplane. Surface reflection was eliminated in the first case by lowering the instrument until the receiving window was just under water. In the second case the radiometer was turned away from the sun and oriented to receive light at Brewster's angle where the reflected light is totally polarized. A polarizing filter was placed over the receiving window so as to cut out all reflected light, thus allowing the instrument to record only the upwelling light from beneath the surface. Preliminary tests in which simultaneous measurements were made as the plane flew over the ship showed good agreement.

Incident daylight falling on the sea surface has its greatest intensity at about 490 mμ. As the radiation penetrates into the clearest water, the peak of the spectral curve tends to move farther into the blue, to 470 mμ or less, but in areas of the sea where more dissolved and particulate matter are present, the region of highest irradiance moves toward the green or yellow. For example, in Massachusetts Bay our curves peaked at 530 mμ and off Woods Hole at 560 mμ. Since plant pigments, particularly chlorophyll, modify the spectrum in characteristic ways, spectral analysis of the upwelling light should reveal areas of phytoplankton abundance provided that sufficiently sensitive instruments are employed. The use of radiometers from airplanes, or space craft, would thus constitute a valuable new tool for the rapid survey of the productivity of oceanic areas.

ZOOPLANKTON TAXONOMY

George D. Grice and Kuni Hülsemann

Our major emphasis last year was directed toward completing analyses of copepods collected by midwater trawl in the southeastern Pacific Ocean in January 1966 and in the Caribbean Sea and Gulf of Mexico in June 1966. We have also devoted considerable time on two cruises conducting a series of field experiments designed to determine the cause and cure of the persistent contamination problem in our deep vertical Nansen net collections.

Pacific Ocean:

In the midwater trawl samples collected between the Chilean coast and a point 1,000 nautical miles offshore we recorded 78 species of calanoid copepods belonging to 11 families. Most are widely distributed species. Sixty-eight percent of them occur in the Indian Ocean and 81 percent in the Atlantic Ocean. Seven of the 78 species have not previously been reported in the Pacific and 6 species were undescribed. A paper concerning these collections has been submitted for publication.

Atlantic Ocean:

The copepods in 46 midwater trawl samples collected in the Caribbean Sea and Gulf of Mexico by Dr. R.H. Backus and his associates were examined. Eighty species of calanoid copepods were identified including 17 new records and 2 undescribed species. They bring the total number of known calanoid copepods in this area of the western North Atlantic to 166. A paper on the copepods in these collections has been submitted for publication.

Contamination experiments:

We have been concerned about the occurrence of typically epipelagic calanoid species in many of our bathypelagic (1,000 m or more) plankton collections and have referred to these species as contaminants. Several of the species which we consider contaminants have also been noted in the deep collections of certain other investigators when vertical type nets were used. So many contaminant species were noted in our vertical collections made off Chile that we did not feel it worth while to examine these collections in detail. It thus became imperative to determine where and under which conditions epipelagic copepods enter the net when collections were made in great depth. Our shipboard activities on two cruises were devoted largely to studying the contamination problem by conducting field experiments with closed nets, open nets, and stained zooplankton. After eliminating the possibility of contamination occurring by (1) washing down the net, (2) copepods adhering to meshes of the net, (3) copepods entering through the closed net, we concluded that zooplankton enters the net through the mouth while it is descending and remains there to be found amongst those organisms which were collected when the net sampled in the upward direction. We now have eliminated the problem of contamination by keeping the net pursed during descent with a pressure-operated release. A paper describing our experiments has been submitted for publication.

Reference Collection:

During the year 396 entries of copepod species were made to the Institution Reference Collection. This includes 6 genera and 48 species which have not hitherto been represented in the collections.

PHYTOPLANKTON PHYSIOLOGY AND ECOLOGY

Robert R.L. Guillard

Carbon-Isotope Fractionation:

Our study, in collaboration with E.T. Degens, J.A. Hellebust (Harvard), and W.M. Sackett (Texas A&M), of fractionation of stable carbon isotopes by *Skeletonema costatum* and *Cyclotella nana* cultures have been completed. Increase in temperature in the range 10°-30°C lowers the δC^{13} difference between cells and HCO_3^- of the medium by ca. 0.35% per degree C when air (0.03 percent CO_2) is bubbled through the growing culture. However, no temperature effect is discernible when 5 percent CO_2 in air is administered at a rapid flow rate, resulting in a pH of 5.8 nor when $NaHCO_3$ is added in excess.

All data support the inference that both species of algae directly utilize molecular CO_2 rather than carbonic acid, bicarbonate, or carbonate. When air CO_2 (0.03 percent) is provided to an algal culture, there is an increasing drain on the molecular CO_2 supply as (1) the culture becomes more dense, (2) pH rises, and (3) temperature increases. Under these circumstances the equilibrium between molecular CO_2 and the pool of ionized species is broken down; ^{13}C-enriched molecular CO_2 is released from the bicarbonate and taken up by the plants. On the other hand, when molecular CO_2 is sufficiently abundant, there is a constant fractionation of ca. 19% between CO_2 and the cells at all temperature levels. Presumably this mechanism operates in nature. Thus, there is no need to postulate temperature-sensitive enzymatic reactions to account for the change in fractionation with temperature.

Limited heterotrophy:

Studies in collaboration with J.A. Hellebust (Harvard) showed that the estuarine diatom *Melosira nummuloides* has a high specificity for uptake of organic substrates. Neither sugars, sugar alcohols, nor organic acids are taken up measurably at 10^{-4} M, but amino acids or the analog α-aminobutyric acid are taken up rapidly at this same concentration. The uptake mechanism is not inducible, and requires energy. While all amino acids are taken up, only 5 of 22 tested allow growth (arginine, glutamine, asparagine, proline, and glutamate). A study was also begun of growth inhibition by certain amino acids and reversal of the inhibition by others. While the results are interpreted in terms of end-product inhibition, they do not fit into known patterns of synthetic pathways, and further studies are needed.

A study was begun on the nutritional requirements of a small green alga, a *Nannochloris* sp., which is unable to grow (or photosynthesize adequately) in the absence of organic substrates. The pigmentation of this plant

is apparently normal. This characteristic may be common in certain habitats, so that study of the physiological deficiency will be pursued.

Pigment studies:

(In collaboration with C.S. Yentsch). Clones of small green algae (*Stichococcus* (?) sp. and *Nannochloris* sp.) with differing pigment complements have proved useful in a special context. Two clones were selected that only differed significantly in pigmentation in that one lacked chlorophyll *b*. By introducing cultures of the two clones into the two light paths of a dual beam spectrophotometer, a difference spectrum has been recorded that is believed to be an accurate representation of the *in vivo* absorption of chlorophyll *b*.

The water-soluable blue pigment of the diatom *Navicula ostrearia* was extracted from mass cultures and preserved by freezing. Preliminary studies, in collaboration with D. Chapman and H.W. Siegelman (Brookhaven National Laboratories) revealed that the pigment has neither the properties of a phycobilin nor of an anthocyanin, which seemed to be the most likely constituents. Other possibilities are being explored.

STUDIES OF THE DEEP-SEA BENTHOS FROM *ALVIN*

Robert R. Hessler

This year *Alvin* was made available for intensive scientific research for the first time. As a result, we were able to make a series of six dives on the continental slope at depths of 1300 and 1900 meters. The two diving sites were on our Gay Head-Bermuda transect, and therefore the results can be integrated with information collected from these areas over the past several years.

This season's efforts concentrated on familiarizing ourselves with the environment by means of direct observation, and evaluating the importance of the large surface living animals. These animals are rarely caught using remote techniques from surface vessels because of the animals' ability to avoid capture or because of their patchy or sparse distribution. Echinoderms and fish were the dominant elements. At 1900 meters the ophiuroid *Ophiomusium lymani* was present in a remarkably even distribution throughout the area of the dives. At 1300 meters, this species had disappeared, and the echinoid *Phormosoma placenta* (Fig. 1) dominated, occurring in large clusters.

On these dives, we were not only able to observe the animals, but could photograph and capture them as well. Using techniques of areal photogrammetry on the hundreds of Edgerton camera photographs taken on each dive, the density of the large surface animals can be plotted. This, combined with measurements of the amount of organic material in the animals captured will allow us to calculate the standing crop of this faunal component.

PHYTOPLANKTON DISTRIBUTION

Edward M. Hulburt

Studies on phytoplankton species have covered a wide area during the past year. Within the Gulf of Maine an entirely oceanic flora composed of coccolithophores and small dinoflagellates was observed in September and at the end of March. A similar flora was encountered on a crossing from Woods Hole to Dakar, Africa, and in a fairly extensive coverage of the eastern Gulf of Mexico. Distinctive features observed in the Gulf of Maine, where samples were taken at various depths every six hours at the same location, were wide variations both vertically and with respect to time in the densities of several species in September. These variations, which were as much as 100-fold, occurred within the thermocline. In March uniformity and paucity of the phytoplankton were characteristic. Features in the plankton distribution across the ocean included a marked decrease in the dominant coccolithophore, *Coccolithus huxleyi,* from north of Bermuda northward, thence a slight increase eastward at 45°W (over the Mid-Atlantic Ridge) and then a further increase in the upwelling region off West Africa (at 20°N). In the Gulf of Mexico surface samples were taken in November and December (1966) showed a fairly uniform flora not only in the deep water but over the wide continental shelf up to the 20-fathom line. The water is stratified below that depth, and this fact accounts for the lack of any effect of the deeper portions of the shelf on the plankton. Within the 20-fathom line larger concentrations and a change in the flora occurred.

Near the Mississippi delta an abundance of the neritic diatom, *Skeletonema tropicum*, was found. This species had been seen before off Jacksonville, at Vera Cruz, at the eastern end of the Panama Canal, near the island

of Trinidad, and just north of the mouth of the Amazon River. Since it has not been observed north of 30°N, where winter temperatures fall below 15°C, and since it will not grow in culture experiments below this temperature, its tropical (or semi-tropical) distribution is defined by its temperature tolerance.

The widely distributed neritic form, *Skeletonema costatum*, has been found dominant in the coastal water of the Gulf of Maine in summer. It is carried down by the active tidal mixing between the islands to a depth of 30 meters. This is deeper than it will grow when enriched samples are anchored at various depths. The partial breakdown of the thermocline, that has been observed between the islands, allows partial mixture of plankton and nutrient and the development of large populations, as is presumably the case in water of less than 20 fathoms in the Gulf of Mexico.

MARINE MICROBIOLOGY

Holger W. Jannasch, Hans G. Trüper, James J. Kelleher, Barbara-Ann Collins, and Grace C. Fraser

Studies on the development of reproducible enrichment techniques in continuous culture for the isolation of characteristic marine bacteria were completed. Within a certain range of dilution rates and concentrations of the limiting substrate, chemostat enrichments were successful. Experimental attempts to separate single species from mixed cultures of known composition showed that successful or unsuccessful competition for the limiting substrate could be expressed by kinetic growth parameters of the individual species under given conditions. Species exhibiting low values of their growth parameters displaced species with relatively high values if the continuous culture was operated correspondingly at low dilution rates and/or low concentrations of the limiting substrates. This behavior is significant for the characterization of those microorganisms actually responsible for the degradation of organic materials in the sea under natural conditions.

Based on the determination of growth parameters, the studies on population dynamics were continued. Mixed pure cultures of marine and non-marine bacterial strains were grown in the chemostat at doubling times up to 100 hours and at various concentrations of the limiting substrate. Predicted displacement times could be confirmed experimentally. We hope to achieve valid estimations of survival times of terrestrial and enteric bacteria in sea water at various environmental conditions.

Forty-one strains of sulfate-reducing bacteria isolated from various deep-sea and estuarine environments were studied and classified. Their characteristics differ considerably, not always corresponding with the recent scheme of classification. In a series of experiments, the question of bacterial sulfate reduction in the Red Sea hot brines was studied. Since no sulfate-reducing bacteria could be isolated from the *Atlantis II* and the *Discovery* deeps and the surrounding sea bottom, an attempt was made to adapt stepwise a variety of strains to growth at elevated temperatures and salinities as found in this particular habitat. The only strains able to grow well at 10% NaCl and 44°C or at half-concentrated brine and 35°C were isolates from the *Atlantis II* deep brine sea water transition zone.

Techniques for studying sulfate reducing bacteria in steady state culture have been established. The problem of ferrous sulfide accumulations in the chemostat and medium outlet has been solved by selecting an isolate requiring unusually small amounts of iron in the medium for growth. The kinetics of substrate- (sulfate) and product- (sulfide) limited growth were studied with the aim of detecting characteristic metabolic differences.

In enzymological studies on marine sulfate-reducing bacteria it was found that polysaccharides were formed via the Embden-Meyerhof-Parnas pathway. When the strain selected for these studies was grown on glucose, the same enzymes were found indicating that the Entner-Doudoroff pathway, typical for pseudomonads, does not occur in sulfate-reducing bacteria. Representative enzyme activities in strains exhibiting different temperature optima were compared after cultivation at 25° and 40°C. Highest activities were measured when test temperature and growth temperature were identical except for some enzymes (e.g., phosphogluco-isomerase) which are stimulated by high test temperatures. The enzyme activities were also measured in extracts from cells grown at 3, 6, 9 and 16 hours doubling times in steady state culture. The activities of some enzymes were considerably higher in cells grown at relatively high rates while the activity of other enzymes appeared to be independent of the growth rate. These studies were done together with Susan W. Tafler, who worked in our laboratory as a summer fellow.

During studies on photosynthetic sulfur bacteria, a new rapid method for the measurement of *in vivo* absorption was developed in cooperation with C.S. Yentsch. Fifty-one strains of photosynthetic bacteria have been isolated and are maintained in our laboratory. Several new species will be described and named. The presence of a key enzyme in the sulfur metabolism (adenosine-phospho-sulfate-reductase) was established in several species in a joint research effort with Dr. H.D. Peck, Department of Biochemistry, University of Georgia. The location of the enzyme in the chromatophore structures was determined after preparative centrifugation. The enzyme activity was measured spectrophotometrically as well as by applying radioactive sulfite and subsequent autoradiography of the reaction product, adenosine-phosphosulfate.

Studies on the occurrence and turnover of glucose in the sea were conducted during *Atlantis II* Cruise 31 on a transect from Bermuda to the upwellings of the Senegal coast in cooperation with S.E. Hicks, R.F. Vacarro, and F.G. Carey. The occurrence of glucose was found to correlate with the immediate uptake of glucose by the natural population of microorganisms.

The occurrence and distribution of obligate anaerobic bacteria in the oxygen minimum layer off Cape St. Lucas, Lower California was studied on *Te Vega* Cruise 13 (Stanford University). Anaerobic spore-formers and sulfate-reducing bacteria were found to occur only in the upper sediment layer in an area where the continental slope meets with the 0.15 ml/l. bracket of the oxygen minimum layer in a depth of 350 to 800 m. The distribution of aerobic and facultative anaerobic (nitrate-reducing) bacteria was not indicative for the location of the oxygen minimum layer.

PHYSIOLOGY OF HUMAN DIVING

John W. Kanwisher

In the continuing study of animal and human diving it is now becoming possible to see why the true marine mammals such as porpoises and seals can do so much better than man. Since they are both air breathers they must hold their breath when going below the surface. How long they can dive depends on how well they can stretch out the limited oxygen supply in their lungs and blood. An essential part of this oxygen saving in a porpoise consists of starving most of the body by cutting off its circulation. Only the heart and brain seem to get the same amount of oxygen as at the surface. Since less blood is being pumped the heart is slowed down, sometimes by a factor of 3 or 4 times. In my past work this has been checked by equipping animals with acoustic transmitters and letting them swim free while sending information about their heart beat.

In man, the heart also sometimes slows when diving, but not nearly as much. My chief work this year has been to determine whether man has any significant ability to orient his circulation and thus increase the length of time he can dive. It now appears that he has not. The principal data supporting this comes from measurements on the rate at which oxygen disappears from the lungs while the breath is being held. Determinations were made on divers at a variety of depths down to 30 meters (4 atmospheres) as well as in the laboratory. In all cases the body drew oxygen from the lungs at a rate close to that which occurred before the dive. So the occasional slowing of the heart must be interpreted as other than essentially a diving reflex. Other respiratory data such as breathing rate, tidal volume, alveolar gas composition, and maximum metabolism have also been determined on divers swimming free in the water. Experiments with exotic gases and use of a mass spectrometer are being added to our work to give such data as cardiac output and to study the general problem of gas transport in diving.

TELEOST HYPEROSTOSES

Andrew Konnerth

In the continued study of the development of hyperostotic bones, the examination of both cleared and stained and soft x-ray plates of young spadefish, *Chaetodipterus faber*, gave some conclusive evidence concerning the basic osteological morphology of some of the skeletal elements that become hyperostotic. It has been speculated that the occipital crest hyperostosis forms above the cranial root and grows downward to make contact with the skull. Examination of the above mentioned specimen shows that there is a very thin bony plate that extends upward from the skull root and between the two muscle masses. Hyperostotic proliferation of bone tissue begins to occur

in the upper posterior portion of this plate when the fish is approximately 15 cm in length. This growth continues so that when the fish reaches a length of ± 25 cm there is a very well developed hyperostosis that is connected to the skull by a thin bone attachment. In older or larger specimens this hyperostosis is firmly attached to the skull roof.

Cross-sections of hyperostotic first and second interhaemals in *C. faber* shows a double "Y" shaped pattern in the center. This pattern was originally the two basic interhaemals that later on became hyperostotic. This study showed that these two interhaemals are joined together in one unit when the specimens are of a length of only 7 mm. It had been previously thought that the first interhaemal becomes hyperostotic and surrounds the second interhaemal. This has been known to occur with the third interhaemal which is entirely independent of the first two.

The comparative skeleton collection of fishes has continued to expand. It now numbers ± 60 specimens, of which roughly one-half are of local species. This material has been useful in identifying isolated bones that have been brought in for identification.

LABORATORY CULTURE AND LIFE HISTORY OF *CENTROPAGES TYPICUS*

Thomas J. Lawson, Jr.

One of the most important autumnal species of zooplankton in the Gulf of Maine is *Centropages typicus.* This moderately large neritic copepod is frequently the most abundant form in surface waters. It ranges over the continental shelf as far south as Cape Hatteras, but is not found inshore where the salinity is low.

A laboratory culture was started in June with adults collected in Block Island Sound. The culture has now been carried through a number of generations of about 25 days each. Observations were made on breeding, feeding behavior, and the time span between each of the eleven successive molts in the copepod's life cycle.

The morphological development of this copepod has been followed and drawings of the appendages of each naupliar and copepodid state have been prepared. All of these developmental stages were also observed in the plankton collections from the Gulf of Maine. Material from several cruises on the continental shelf has been examined for further information on the distribution and life cycle of this species.

ZOOPLANKTON IN THE GULF OF MAINE

Thomas J. Lawson, Jr.

During four cruises to the Gulf of Maine in 1967 (*Atlantis II* Cruise 26 in early September, *Chain* Cruise 65 in March and April, *Crawford* Cruise 159 in early August, the *Crawford* Cruise 164 in November) studies were made of the composition and diurnal vertical distribution of the zooplankton community. This sampling program was insufficient to give a full account of the seasonal fluctuations in the zooplankton distribution but it indicated the range of variability during the year.

For each cruise, a parachute drogue was launched at about the same location in the Gulf of Maine. Most collections were made near the drogue so that, currents notwithstanding, the samples from any one cruise would represent the same community.

The water column, somewhat over 200 meters in depth, was divided into 50 meter intervals for sampling. A closing net (#6 mesh) was used to avoid contamination with plankton from shallower depths when subsurface samples were collected.

The minimum amount of zooplankton was found in the spring when there was a mean displacement volume of about 0.05 cc per cubic meter. The spring phytoplankton bloom had not yet commenced and there were few eggs or juvenile zooplankters. However, *Calanus finmarchicus,* which overwinters in copepodid stage V, had molted into the adult form as a prelude to spring breeding.

The maximum biomass of about 0.23 cc per cubic meter occurred in late September. At this time, as well as in the summer and late fall, the zooplankton community was composed mostly of juvenile copepods. *Calanus finmarchicus* was already molting into the overwintering stage V in September and this process was essentially completed by November.

Through most of the year the biomass was concentrated in the surface and bottom 50 meter sampling intervals except in March when the distribution was nearly uniform. However, these concentrations shifted somewhat during the course of a day due to diurnal vertical migrations, especially between the 0-50 and 50-100 m levels. In August, about 75% of the biomass at the 50-100 m interval in the daytime migrated into the surface waters at night. The corresponding figure for late September was about 30%. The pattern of vertical movement was not so clear and of smaller extent in the spring and in November.

VERTICAL DISTRIBUTION OF CHLOROPHYLL DERIVATIVES

Carl J. Lorenzen

Studies have been carried out on the vertical distribution of both chlorophyll and chlorophyll derivatives. The major derivative seems to be phaeophorbide. Highest concentrations of these pigments are found in the upper layers of the water column, i.e., the euphotic zone, as should be expected since they are either found inside living phytoplankton cells or phytoplankton debris. The processes contributing chlorophyll derivatives to the water are of interest for a number of reasons. If phytoplankton cells should die, and their chlorophyll be converted to phaeopigments (chlorophyll without its Mg), it would indicate that the food chain in the area is operating at something less than optimal efficiency. These phytoplankton cells, however, might serve as a food source for bacteria with a resulting remineralization of nutrients *in situ* thereby retaining them in the euphotic zone. Although this process might not result in an increase in the zooplankton biomass or high steps in the food chain, at least the nutrients would not be lost to the productive cycle. On the other hand, the phaeo-pigments may represent phytoplankton which has passed through the intestinal tracts of zooplankton organisms, thereby providing an index for the rate of grazing relative to phytoplankton production. These alternatives were tested in the laboratory. Different phytoplankton cultures were held in both light and dark situations for varying periods of time. Phaeo- pigments did not appear in either case, whether the cultures were septic or aseptic, suggesting that bacterial action could not produce phaeo-pigments. Zooplankton feeding on algae, on the other hand readily produced phaeo-pigments, the major constituent of which appeared to be phaeophorbide, producing approximately one-third as much phaeopigment as the chlorophyll that was ingested.

The problem was further pursued in the field. The abundance of phaeo-pigments was not constant, and the ratio of chlorophyll to phaeo-pigments varied. Phaeo-pigment were abundant relative to chlorophyll only when the absolute quantity of chlorophyll was low. On the other hand, phaeo-pigments bore a direct relationship to the quantity of small zooplankter (less than 5 cm in length). Interestingly enough, photosynthetic efficiency (the quantity of carbon fixed during photosynthesis per unit of chlorophyll) was highest when the relative quantity of phaeo-pigments was greatest. This situation also concurred with the highest ratio of small zooplankton to chlorophyll. Thus we have the interesting situation of a relatively low phytoplankton population photosynthesizing at a maximum optimal rate, but being grazed down as fast as it is growing. Although the system is very efficient, production on a unit area basis is lower than inshore where much larger though less efficient phytoplankton standing crops are found.

DISTRIBUTION, MIGRATIONS AND MORPHOLOGY OF LARGE PELAGIC FISHES

Frank J. Mather III and Martin R. Bartlett

Our main effort was again devoted to marking large oceanic fishes. In the Atlantic, 2,305 fish were tagged including 93 giant and 628 small bluefin tuna, *Thunnus thynnus*, 451 white marlin, *Tetrapturus albidus*, 779 Atlantic sailfish, *Istiophorus albicans*, and 229 greater amberjack, *Seriola dumerili*. Returns were obtained from one giant and 697 small bluefin tuna, five white marlin, 14 Atlantic sailfish, and 37 greater amberjack. Releases were far fewer than in 1966, especially for bluefin and skipjack (*Katsuwonus pelamis*) tunas, but the returns were the most numerous of any year, and included many of unusual interest. Some istiophorid fishes were tagged in the Pacific, but this phase of the program is now being conducted mainly by the Tiburon Marine Laboratory.

Transatlantic migrations were recorded for one giant bluefin, from the Straits of Florida to Norwegian waters, and for 16 small individuals, from the New Jersey-Cape Cod area to the Bay of Biscay. The former was

released in May, 1967, and recaptured 82 days later; five of the latter had been marked in the summer of 1965, and eleven in the summer of 1966. These itineraries are consistent with those previously recorded for bluefin of similar sizes. Transatlantic migrations of giants evidently occur mainly within summers, and those of small fish, between summers. The return rates and the commercial catches on the respective sides of the ocean in 1966 and 1967 suggest that fewer fish crossed from west to east between the 1966 and 1967 seasons than between those of 1965 and 1966.

Our catch, effort and size sampling data for the northwestern Atlantic tuna purse seine fishery in 1967 showed increases in the number of vessels, and in the tonnage and average age of the catch of bluefin tuna, compared with the 1966 season. On the other hand, the catch of skipjack tuna was negligible, and the recruitment of one-year-old bluefin was the poorest in recent years.

Local returns for young bluefin included 15 percent of the 1967 releases, 14 percent of those of 1966, and 2 percent of those of 1965. The relatively large numbers of returns from fish which had been at large for one and two years shoud permit better estimates of population parameters. Tagging mortality has evidently been much higher for bluefin released from seine catches than from those tagged by sport fisherman. Returns from the 1965 releases include 15 percent of the former and 40 percent of the latter, and those from 1966 releases, 27 percent of the former and 42 percent of the latter. These figures indicate very heavy fishing pressure on the northwestern Atlantic stock, especially since nearly all of these fish were only one or two years old when released, and the bluefin is a relatively long-lived fish.

Four white marlin released in various summers (1964-1966) off Maryland and southern New Jersey were recaptured off Venezuela in January, off French Guiana in February, off Havana in May, and east of Georgia in May, respectively. These returns are generally consistent with the previously proposed clockwise migratory cycle for the fish which summer off our middle Atlantic coast. However, the recapture off South Carolina in June, 1967, of an individual marked off Venezuela in October, 1965, suggests that white marlin do not necessarily spend each summer in the same area.

Sailfish returns gave considerable further evidence of migrations between temperate and tropical areas. Two of these were between the northeastern Gulf of Mexico and the Straits of Florida, and one from off Jacksonville, Florida, to the latter area. Two individuals tagged off the Virgin Islands early in 1967 were recaptured in June, one in the Gulf and the other off South Carolina.

Many greater amberjack marked off southeastern Florida and the Bahamas were recaptured locally. Five tagged near Jacksonville in July and August, however, were recapture in the former area between February and May. The longest migration yet recorded for the species was from off northern Florida in May, 1964, to near Santa Marta, Colombia, in October, 1967. These reulsts, like earlier ones, indicate that some greater amberjack remain in restricted habitats in tropical waters, but others make considerable seasonal migrations.

Studies of the systematics and distribution of fishes of the genus *Seriola* continued, with participation by David Shores in examining specimens and Martha Howbert in preparing illustrations. New developments include a possible new species from the eastern Atlantic, the first records of *S. lalandi* from Argentina, and of *S. dumerili* from the eastern Pacific.

Prior to his departure in June, Martin Bartlett investigated the occurrences of broadbill swordfish *Xiphias gladius* in relation to water temperature structure. He also participated in *Atlantis II* Cruise 31 in the South Atlantic in February and March. He is preparing to publish with Dr. R.L. Haedrich on the distributional pattern of larval blue marlin, *Makaira nigricans*, and the design of the neuston nets in which 35 of these were collected during this cruise.

ORGANIC CARBON

David W. Menzel and John H. Ryther

Three hypotheses may be advanced to explain the concentration of dissolved organic carbon (DOC) in the deep-sea: (1) that DOC behaves as a "conservative" property and that its concentration is essentially unchanged once a particular water mass reaches a critical depth; thus all decomposition which occurs does so rapidly at the

time of deepwater formation; (2) that following an initial rapid oxidation of easily decomposed compounds long term *in situ* decomposition continues to occur at depth; and (3) that concentrations may be influenced by the sinking and decomposition of surface produced particles. In order to test these alternatives a cruise was made to the South Atlantic (*Atlantis II* Cruise 31, March, 1967) during which particular attention was paid to vertical and spatial variations in the concentration of organic matter.

Below a depth of 400 cm, all values of DOC were the same within previously stipulated analytical precision. The concentration of oxygen along the same section varied greatly, with a well-defined minimum occurring at the northern end (10°S) between σ_t 27.0 and 27.2. This oxygen minimum could be traced toward the south following the same density surfaces until it was strongly attenuated by high oxygen water of southern origin, appearing at 25°S as a vertical maximum. *In situ* changes in oxygen of 3.69 ml/l. were detected in a S-N direction at σ_t 27.2, equivalent to the oxidation of approximately 1.4 mg carbon/l. It was previously noted that the maximum observed difference in DOC was ± 0.1 mg l. an insignificant fraction of the organic matter necessary to produce the measured alterations in oxygen.

Another form of organic matter which could, through its decomposition, contribute to the formation of intensification of oxygen minima is particulate matter, either settling from the surface or transported horizontally by advection. In the former case an exponential decrease in concentration with depth might be expected, whereas in the latter differences in concentration would presumably appear latitudinally as one follows the progression of a given water mass. The values for particulate carbon in both vertical and horizontal profiles exhibited minor variations below 400 m which may, as in the case of DOC, be attributed mainly to sampling and analytical error (± 5 μg C/l.). Apparently, therefore, major differences in oxygen in both vertical and horizontal sections below 400 m cannot be atrributed to the oxidation of either DOC or particulate carbon.

An alternate explanation to account for changes in the concentration of oxygen without corresponding changes in organic carbon is that two water masses containing unequal oxygen but equal carbon concentration mix. That this may occur in the region studied was suggested by the presence of two distinct regions of low- and high-oxygen water, respectively, which appear to be moving in opposite directions between σ_t 27.0 and 27.2. The highly oxygenated northward flowing water, also readily identified by its low salinity, is the Antarctic Intermediate Water centered at about 1000 m at the southern end of the section and rising to 700-800 m at the northern end. Above this is a southerly-flowing surface water mass, which contains the oxygen-minimum layer, at a depth of 300-400 m at the northern end and at 400-500 m near the center of the section, where its identity becomes obscured. Mixing between these superimposed and opposite-flowing water masses could be expected to increase the oxygen content of the oxygen-minimum layer while decreasing that of the Antarctic Intermediate Water.

On the basis of changes in salinity of southern boundary water toward northern boundary conditions, dilutions were calculated by the "core" method and, from these, oxygen concentrations were predicted at each intermediate station. The results of these computations show that major alterations in oxygen in the core of the Antarctic Intermediate Water may be attributed to mixing alone. As there was no suggestion of changes of the concentration of DOC, it follows that both oxygen and DOC in deepwater behave essentially as "conservative" properties of sea water.

The decomposition of organic matter obviously must occur at some stage in the history of a water mass in order to produce deficits in dissolved oxygen. Since significant biochemical alternations could not be demonstrated in the data discussed above, it is apparent that oxygen utilization must have occurred early in the history of the water masses considered. In order to maintain consistency in our interpretation all oxidation of organic matter must take place in the upper 400 m, the level tentatively identified by higher levels of DOC than observed below that depth. Oxygen depletion here may occur due to the penetration and decomposition of sinking particles. Depth limits of 300-400 m for the initial development of the oxygen minimum are maintained along the previously mentioned coastal region and throughout the entire tropical Atlantic. To the north and south the level of the oxygen minimum deepens along σ_t surfaces 27.0 - 27.2. Further studies will test the thesis that the oxygen minimum is formed entirely in the tropical Atlantic and that low oxygen water is thereafter distributed horizontally along isentropic surfaces, mixing with higher oxygen water to the south and north but not further accentuated by *in situ* decomposition of organic matter. More recent analysis of data from *Anton Bruun* Cruise 33 off Chile suggests

further that the production of the oxygen minimum may be restricted entirely to the coastal regions of upwelling.

The conclusions reached above result entirely from a consideration of hydrographic observations and therefore apply only to dominant controlling factors. They argue against the decomposition of organic matter at depth only to the extent that these processes did not appear to have a significant effect on measured *in situ* concentrations of oxygen and dissolved organic carbon.

COMPARATIVE BENTHIC DIVERSITY

Howard L. Sanders

A comparative study of bottom fauna was carried out on the diversity of the soft-bottom habitat in high and low latitudes, shallow water and the deep-sea, and marine and brackish environments. Identical procedures and sampling techniques were used. The greatest diversity was observed in environments with narrow physical variability and long historic stability as exemplified by the deep sea and certain tropical shallow water situations. The lowest diversity was found in physically unstable and variable environments such as estuaries, some shallow boreal, and a few tropical shallow water areas.

A stability-time hypothesis was proposed to explain these findings and this, in turn, allowed us to predict the diversity in environments as yet unstudied. One prediction states that there are two fundamentally different types of boreal shallow-water communities, one dominated by a continental climate and with low faunal diversity, the other characterized by a maritime climate and with appreciably higher diversity. Studies carried out during the summer of 1967 in the Puget Sound region, when compared to earlier investigations along the New England coast, followed this prediction.

DISPERSAL OF LARVAE IN THE EQUATORIAL ATLANTIC

Rudolf S. Scheltema

A number of stenothermal benthic species are restricted to the shoal-water tropics and yet are known to have amphi-Atlantic distributions. One explanation for such a distribution is the dispersal of larvae over long distances. Teleplanic* larvae are transported across the tropical Atlantic from West Africa to South America by the North and South Equatorial currents. This is deduced by the distribution in the open sea of larvae from a large number of shoal-water species (Scheltema, in press). The larvae of stenothermal species however ordinarily will not survive the temperatures of 20°C and less that are encountered in the North Atlantic drift. Consequently, unlike a number of eurythermal tropical forms (Scheltema 1964, 1966a, 1966b; Scheltema and Hall 1965) they cannot utilize the North Atlantic drift for an eastwardly dispersal. The question then arises as to the means by which this can be accomplished by western Atlantic species.

In 1886 the hydrographer J.Y. Buchanan described before the Royal Geographical Society "the very remarkable undercurrent setting in a southeasterly direction with a velocity of over a mile per hour" and flowing directly underneath the equator from South America toward Africa. This undercurrent, subsequently designated the Atlantic Equatorial Undercurrent has been recently rediscovered and extensively studied during an international expedition known as Equalant. It flows at a depth of between 60 and 90 meters at velocities varying from 1 to 5 km/hr (Metcalf, Voorhis and Stalcup 1962; Rinkel, Sund and Neumann, 1966; Stalcup and Metcalf 1966; and Khanaychenko *et al.* 1965). The core of the undercurrent is characterized by more saline water exceeding 36 parts per thousand and a temperature more than 25°C (Fig. 1).

During the cruise of *Atlantis II* in the equatorial Atlantic, a series of plankton tows were made with closing nets in the undercurrent. These tows showed that the larvae of a large number of stenothermal species are commonly found both in the undercurrent and in the surface water (Scheltema 1967). An interesting example is the Semper's larvae of a species of zoanthid coral, probably belonging to the genus *Palythoa*. These corals are common in the shoal waters of the tropics and have never been found in temperatures of less than 20°C (Fig. 2). The evidence shows that larvae of stenothermal shoal-water tropical forms may be transported in either direction in the tropical Atlantic; westwardly on the North and South Equatorial currents and eastwardly on the sub-surface equatorial undercurrent.

*This term from the Greek *Telep'lanos* meaning far-wandering is suggested to replace the cumbersome expression "long distance" larvae (Scheltema, in press).

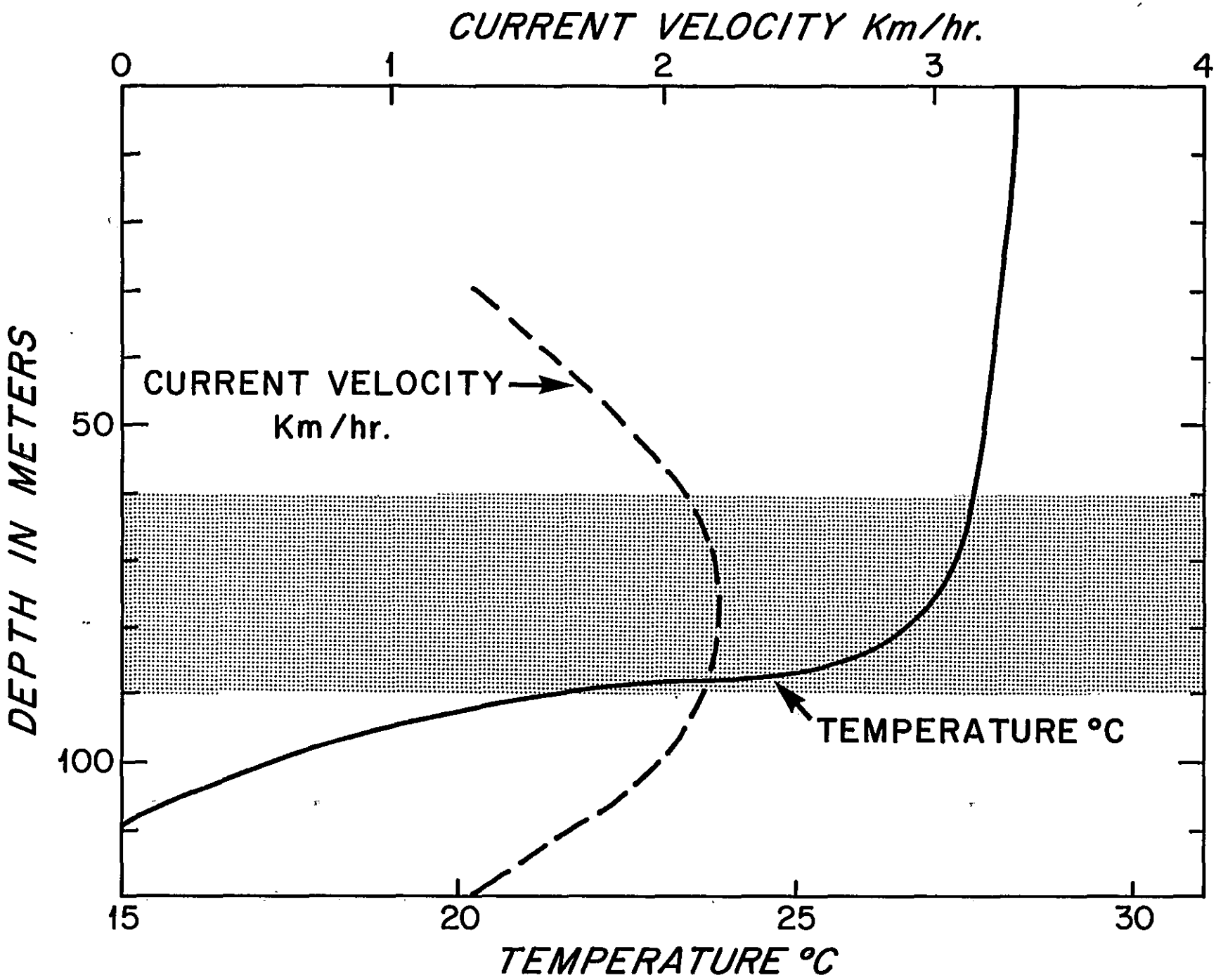

Fig. 1. (Scheltema) Temperature and current velocity in the Equatorial Undercurrent in the region between 25° and 32°W latitude. Temperature data are from bathythermograph lowerings made at the time the plankton samples were collected. Velocity data are averages computed from Stalcup and Metcalf (1966). Shaded area indicates the core of the undercurrent as determined by salinities exceeding 36‰.

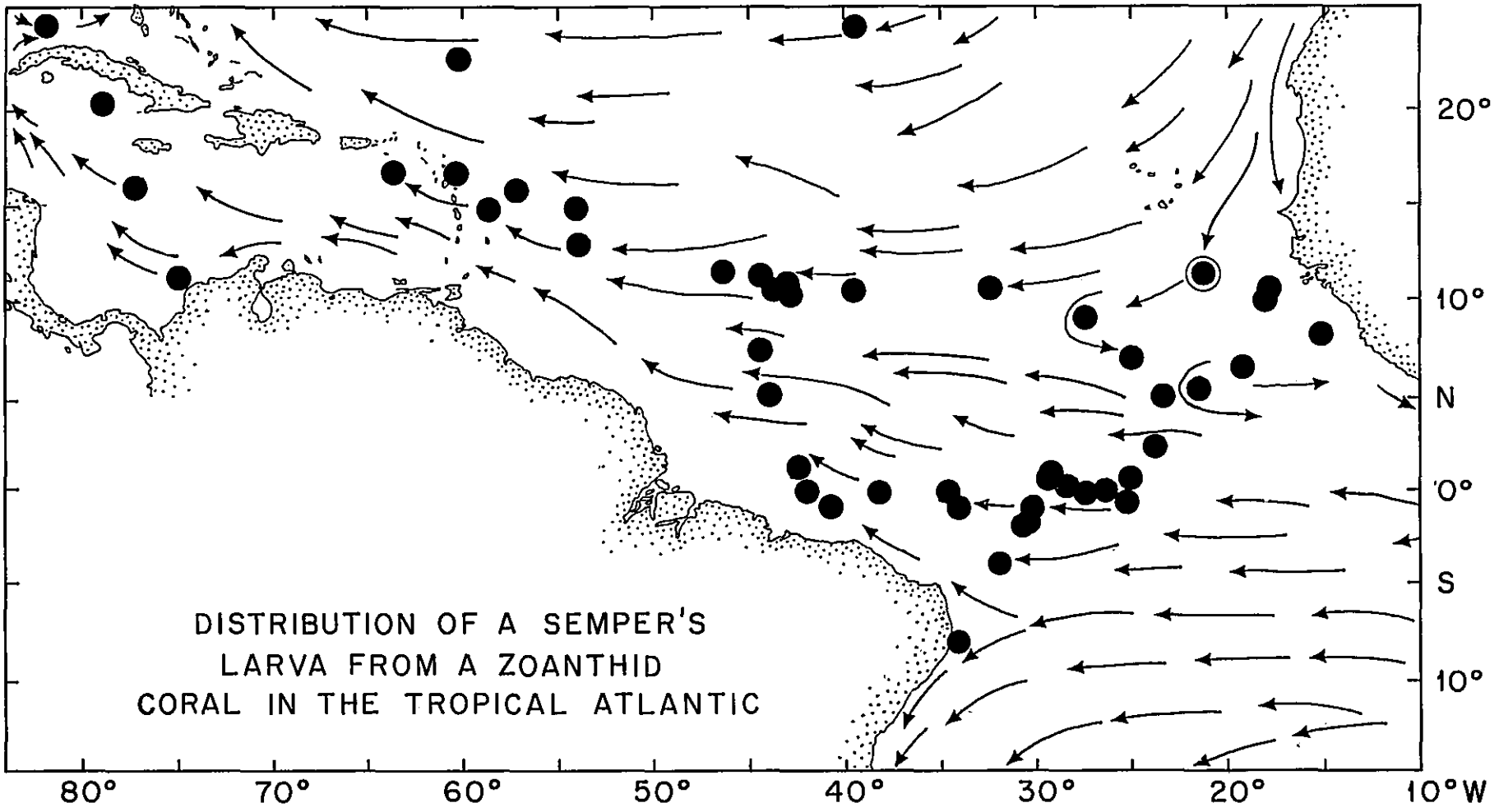

Fig. 2. (Scheltema) Distribution of Semper's larvae from a zoanthid coral taken in plankton tows throughout the equatorial Atlantic.

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PLANKTON COPEPODS

Tai S. Park

During the past year I have undertaken the analyses of the zooplankton samples collected by Dr. George D. Grice from *Chain* Cruise 60 in the Caribbean Sea and Gulf of Mexico. At each station the samples were collected from several depth intervals (100-0 m, 200-100 m, 500-200 m, 1000-500 m, 2000-1000 m and 3000-2000 m) in order to observe the vertical distribution. For two stations all the samples from these depth intervals were examined, identifying all the species present and counting all the individuals in each species. For the other stations only certain samples were analyzed for the determination of species. In all, 162 species of calanoid copepods were identified including 23 new species and 54 species new to the areas. All the new and poorly known species were fully illustrated for publication.

Detailed studies of the external anatomy produced several interesting findings. The specimens referable to *Spinocalanus spinosus* Farran, 1908, fall into 7 distinctive groups, which are readily recognizable by the body size and the structure of the maxilliped. Although it has not been decided whether these groups are separate species, it seems to be unlikely that they all belong to a single species.

A form of the genus *Haloptilus*, anatomically almost identical to *Haloptilus longicirrus* Brodsky, 1950, but distinguishable from the latter by the body size, was found. This form was also separated from *Haloptilus longicirrus* in its vertical distribution, the former being mainly found at the 500-200 m depth interval and the latter below 1000 m at most of the stations. This situation possibly represents an example of an incipient speciation achieved by the separation in the vertical distribution.

As already found by Grice and Hülsemann (1965 and 1967) in the North Atlantic and Indian Oceans, most of the deep-sea copepods found during the present study consist of cosmopolitan species. This certainly reflects the uniform environmental conditions prevailing in the deep-sea throughout the world.

PRESSURE EFFECTS ON BIOLOGICAL SYSTEMS AND INSTRUMENTATION

John M. Teal and Francis G. Carey

Hydrostatic pressure has been shown to have an effect on the metabolism of whole animals, but we do not know what enzyme systems are affected by the pressure. Although the effect on an enzyme system *in vitro* would not necessarily be the same as that in the intact animal, we thought it worthwhile to investigate at least one system. We chose lactic dehydrogenase (LDH) as being both relatively simple to analyze and important in the metabolism of the animals.

Work done in previous years had shown that the activity of this enzyme from abdominal muscles of the vertically migrating euphausid, *Thysanopoda monacantha,* was not affected by pressure changes in the range encountered in its daily migrations between 200 and 1000 meters. The activity of the enzyme was affected by pressures of 670 atmospheres which produced a decrease of activity at 15 and 25°C and an increase at 5°C. The changes were about 25%.

In the eastern Pacific we measured the effects of pressure on activity of LDH from fish and mammals. We used white muscle from the mackerel, *Scomber japonicus,* as a representative surface living fish; muscle from two vertically migrating fish, *Vinceguerria* sp. and a myctophid (neither of which has yet been identified); and from a mesopelagic fish, *Ectreposebastes imus.* As was the case with the euphausid, we found no significant pressure effects at ecologically significant pressures, although all of the fish LDH showed a slight increase in activity (10-20%) at 670 atmospheres. *Vinceguerria* showed this increase at 10°, 20° and 30° while it only appeared at 30° for the mackerel, myctophid and *Ectreposebastes.* Comparative experiments with LDH from rabbit muscle and beef heart showed no effect of pressure on enzyme activity.

An attempt was made to measure respiration of deep sea benthos during Cruise 31 of *Atlantis II.* A few measurements were made but the trawl catches were very poor and not many animals were available. During the summer A. G. MacDonald, University of East Anglia, worked with us on the effects of pressure on various types of oxygen electrodes. The standard teflon-covered electrode which we normally use shows a 30 to 40% decrease in current on compression to 500 atmospheres which requires 15 minutes to reach a steady state. This makes the electrode unsuitable for short-term experiments at high pressures. Silicone rubber-covered electrodes were found to be relatively resistent to pressure but were unsuitable because of electrolyte leakage, a negative current produced in the absence of oxygen, and an overshoot that occurred when oxygen concentration was varied.

Electrodes without membranes, using a silver-silver chloride reference, proved to be suitable. The platinum surface was covered with filter paper held in place by a piece of plankton netting to reduce stirring effects. This electrode proved to be stable (the current decreased less than 0.3%/hr) for periods of at least 60 hours. Compression to 500 atmospheres caused less than 5% change in current output which returned to its previous value within 5 to 10 minutes. Such naked electrodes will be ideal for short-term experiments at high pressures as well as for lowering into the water to obtain *in situ* records of oxygen concentration versus depth.

MARINE FOULING IN THE OPEN OCEAN

Harry J. Turner, Jr.

Severe fouling by goose barnacles has been found near the surface on all structures between Cape Cod and Bermuda. Accumulations and growth of organisms occurs in a few weeks and can alter the calibration and even stop the action of rotors on current meters. Significant accumulations occur only in the top few meters but occasional goose barnacles have been found as deep as 80 meters. Light accumulations of hydroids have been found at all stations occasionally to a depth of 500 meters but growth is so slow that no significant interference with instruments is likely to occur for exposures of many months.

Fishbites have been recorded from the surface to over 2000 meters. Near Bermuda the peak of biting occurs between 900 and 1000 meters and in long exposures approximately 8 bites occur per day, on the average. Tooth fragments secured by H. J. Turner and B. Prindle have been identified by R. Haedrich as those of *Sudis hyalina,* a little known paralepidid fish which is occasionally taken in plankton tows as juveniles. One full set of teeth has been obtained from a pine panel at 1000 meters. An attempt to catch mature specimens with deep long lines baited with luminescent lures was unsuccessful because of loss of gear in a storm.

HETEROTROPHIC ACTIVITY AND PRIMARY REGENERATION IN THE OCEAN

Ralph F. Vaccaro

The use of substrate uptake kinetics to investigate natural heterotrophic behavior by aquatic microplankton is becoming increasingly popular. This trend doubtlessly will continue since the recommended procedures promise an improved understanding of such important environmental parameters as rates of assimilation, efficiencies, and turnover times for representative organic substrates. During the past three years we have attempted to examine and interpret the uptake kinetics for selected organic substrates at a wide variety of oceanic locations.

Marine bacteria and to a lesser extent the plankton algae are believed to account for most of the heterotrophic activity in the oceans. The relatively high heterotrophic rates which are generally associated with estuaries, coastal waters, and the phototrophic layer are believed to reflect significant concentrations of available organic substrates contributed by both terrestrial and marine plants.

The average dissolved organic carbon content of the sea is about 0.75 mg/l. of which a small but unknown fraction is believed to represent carbon in labile form. The remaining and major fraction presumably represents a refractory, humus-like residue resistant to bacterial decomposition. That maximum concentrations of organic solutes rarely exceed 1.5 mg/l. in the open ocean suggests the presence of an indigenous microbial flora capable of assimilating carbon from a variety of sources and at extremely dilute concentrations. These considerations tend to rule out the likelihood of meaningful heterotrophic measurements from experimental designs employing excessively high substrate concentrations and extended periods of incubation. As an alternative method, the uptake of selected ^{14}C labeled substrates provides improved sensitivity and insures a much better approximation of actual conditions in the sea.

Unlike measurements of primary production for which a single source of labeled inorganic carbon suffices, natural heterotrophic activity involves an indeterminate number of biochemical responses to a variety of organic substrates. Few, if any, of these are at present measurable by direct chemical methods. For this reason we are currently devoting much effort toward the development of bioassay techniques employing known ^{14}C labeled organic substrates to measure the natural occurrence of soluble labile organic substances in the sea.

Precise or comprehensive assessments of heterotrophic behavior cannot be obtained by studying the response of natural populations to any single substrate. Rather, appropriate organic substrates must be evaluated independently following their selection in accordance with the best information available on their role in the sea.

To date, shipboard observations using glucose as a substrate have been completed at more than 200 locations which cover extensive areas of both the Atlantic and Pacific Oceans. These data show that no single kinetic standard uniquely characterizes the glucose response of natural marine populations. Saturation-type patterns amenable to analysis by the Michaelis-Menten equations appear most common in embayments and near shore waters of the eastern Atlantic Ocean. On the other hand, samples from the southeast Pacific off Peru, whether inside or outside areas of active upwelling, often provided S-shaped uptake patterns (linear in semi-log plots) which were entirely unrelated to the Michaelis-Menten expression. A third category of uptake responses applies to mid-Atlantic water from the upper 100 meters. A transect along Latitude 15°N extending from east of Bermuda to within 200 miles of the African coast provided thirty observations which failed to show any significant uptake of glucose (less than 0.01×10^{-1} μg C/l./hr) after the standard exposure period. Finally, the occurrence of irregular uptake patterns which appear to represent enhanced activity by multiple species at optimal ranges of substrate concentrations has also been recorded at locations immediately off the African coast.

We have consistently noted marked changes in kinetic patterns following storage of water samples with or without supplementary aeration or nutrient addition. Even samples which fail to demonstrate any initial response to glucose assume characteristic uptake patterns if the analysis with glucose is delayed for ten or more hours. In cases where non-uniform or sigmoid uptake initially occurs, glucose enrichment tends to favor a shift to patterns more indicative of glucose activity by a reduced number of species. Such behavioral changes are in keeping with previous demonstrations that abrupt increases in bacterial counts and dramatic changes in species composition are common in the microbiology of stored water samples.

The effects of bacterial enrichment procedures with or without the addition of supplementary nutrients have been shown to modify original patterns describing natural heterotrophic behavior. Besides the likelihood of

changes in species composition, other pertinent possibilities include (1) provision of an essential induction period to initiate enzymatic activity, (2) removal of a preexisting inhibitory situation with respect to enzymatic behavior. An evaluation of these factors will likely require detailed enrichment studies with mixtures of selected pure cultures rather than resultant uptake observations with nonprecise mixed populations.

Independent estimates of natural substrate concentrations are considered an integral part of our heterotrophic analyses since substrate availability can obviously control the *in situ* rates and mode of enzymatic responses. Seldom are direct chemical analytical methods sufficiently sensitive for this purpose and concentration procedures often introduce undesirable chemical distortions. Even if all the labile carbon in the average sea water sample were to occur in the form of acetate (40% carbon), then the minimum sensitivity of a useful potential analysis would have to exceed 1×10^{-6} moles per liter. Such dilute concentrations are more amenable to measurement with bioassay or biochemical procedures employing whole cells or pure enzyme systems. Besides extremely high efficiencies toward specific substrates the assay method selected must demonstrate a stable uptake behavior over a definable experimental time period. With cellular assays this introduces considerable uncertainty since prolonged cultural storage often imparts an unfavorable influence on the uptake efficiency of test organisms.

Our culture collection now includes marine species capable of utilizing d-glucose, lactic acid, malic acid and phenylacetic acid as sole carbon sources at concentrations typical of sea water. Each of these cultures is a potentially useful assay species although only the glucose assay has been extensively applied at this date (ca. 100 completed analyses). Our results describe oceanic glucose concentrations ranging from 0-100 μg C/l. (mean ca. 8 μg C/l.) with consistently higher concentrations near the surface. When interpreted in conjunction with glucose uptake measurements, our data show that resident microplankton fail to give an immediate response to experimentally added glucose, if *in situ* glucose is either absent or reduced to trace amounts.

MARINE MICROBIOLOGY

Stanley W. Watson and Charles C. Remsen

Long term studies were continued on the ecology, culture, morphology and biochemistry of marine nitrifying bacteria. New methods were devised to enumerate and culture these organisms from the ocean permitting us to estimate their role in the ocean with greater accuracy. Isolation studies were continued and a total of 130 strains, 1/3 of which are in pure culture, are now maintained in our laboratory. Two new genera and three new species of nitrifying bacteria were found. An electron micrograph of one such bacterium, *Nitrococcus* sp. is shown in Fig. 1.

A major problem in the maintenance of cultures has been solved by the installation of a liquid nitrogen storage facility. We have shown that it is possible to store all cultures of nitrifying bacteria, apparently indefinitely, in liquid nitrogen. Such storage, in addition to representing financial and labor savings, insures that the cultures will not be lost or changed genetically. We are also working with Dr. Robert Guillard on the feasibility of storing his algal cultures in a similar manner.

Cooperative studies were carried out with the chemists and geologists on the hot brines of the Red Sea. We found that these brines were sterile and this is the first area of any ocean shown to be void of life. This allows us to examine for the first time, chemical changes free of biological changes in the ocean.

In another cooperative investigation we studied the fine structure of a new photosynthetic bacterium, *Ectothiorhodospira mobilis*, with Dr. Hans G. Trüper. Figures 2, 3 and 4 present the general interior and exterior view of this organism which was isolated from a salt flat on the Galapagos Islands. The highly organized, "chloroplast-like" structures in this organism are unique and may represent an evolutionary link between the chloroplasts found in true plants and the simple photosynthetic organelles found in other bacteria. A three dimensional model of the "chloroplast-like" organelle of *E. mobilis* has been constructed (Fig. 5) to show its similarity to true plant chloroplasts.

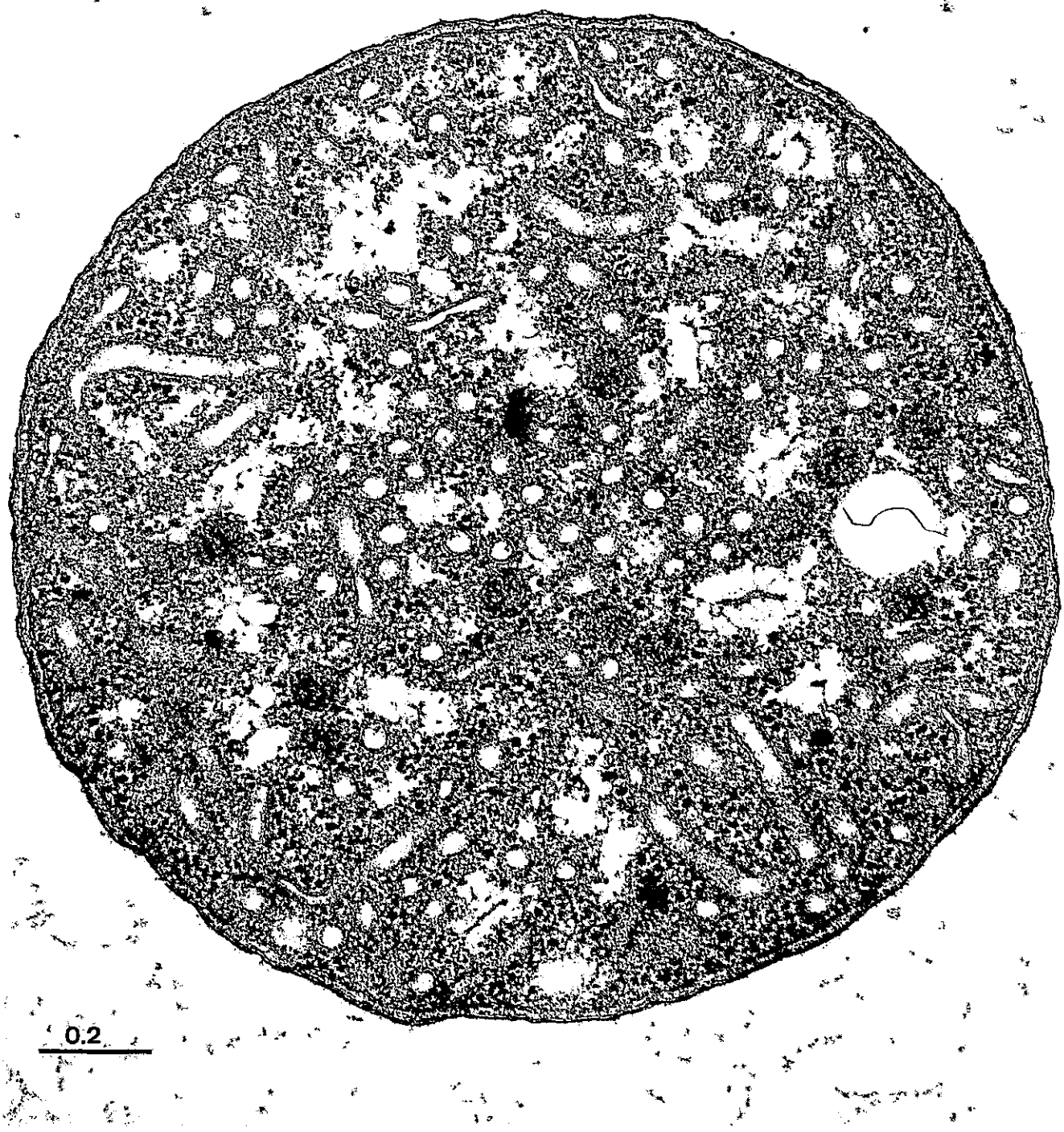


Fig. 1. (Watson) An electron micrograph of a newly-discovered nitrifying bacterium, *Nitrococcus* sp., which oxidizes nitrite to nitrate in the ocean. x 102,200.

Fig. 2. (Watson) An electron micrograph of a marine photosynthetic bacterium, *Ectothiorhodospira mobilis*, showing complicated "chloroplast-like" structures (C). x 60,000.

Fig. 3. (Watson) An electron micrograph showing arrangements of membranes in the "chloroplast-like" structure of *Ectothiorhodospira mobilis.* x 300,000.

Fig. 4. (Watson) An electron micrograph showing the external surface of the photosynthetic bacterium, *Ectothiorhodospira mobilis*. This unique view was made possible by use of the freeze-etching technique. x 95,000.

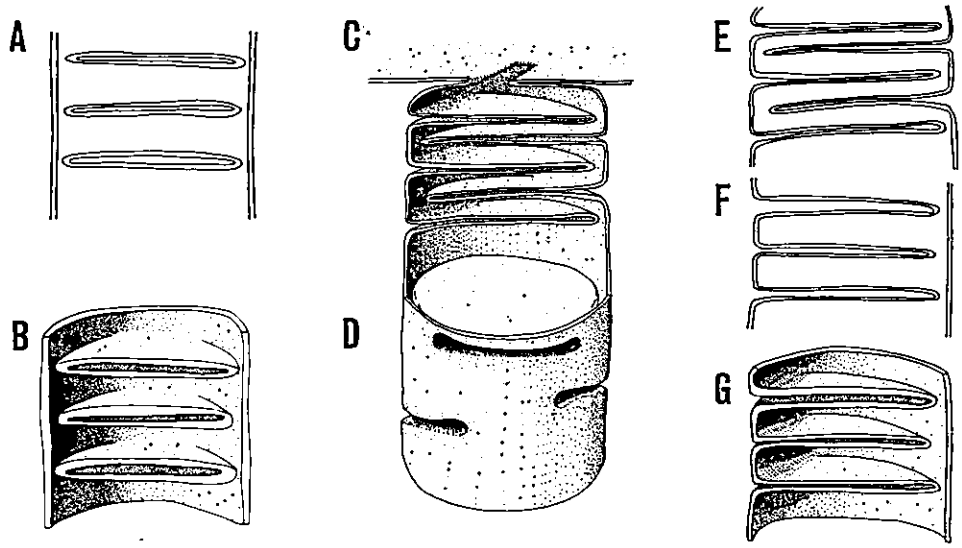


Fig. 5. (Watson) A schematic drawing illustrating the organization of the "chloroplast-like" organelle of *Ectothiorhodospira mobilis.* This structure is formed by the primary and secondary infoldings of the plasma membrane as illustrated in the two and three dimensional drawings A-G.

CHEMISTRY

DEPARTMENT OF CHEMISTRY

John M. Hunt, Department Chairman

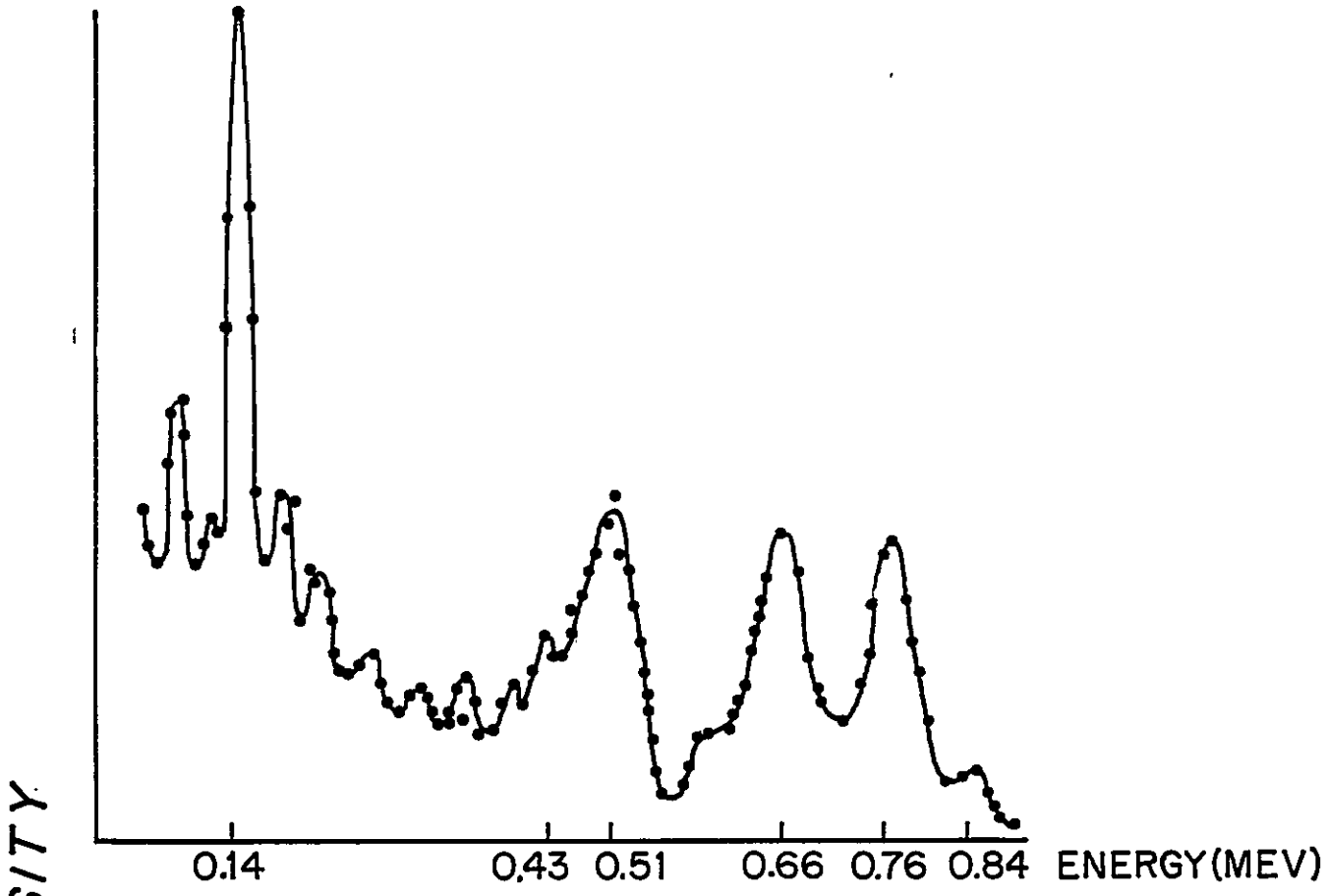


Fig. 1. (Noshkin) Gamma spectrum of air filter sample 34 collected 22-24 June 1965.

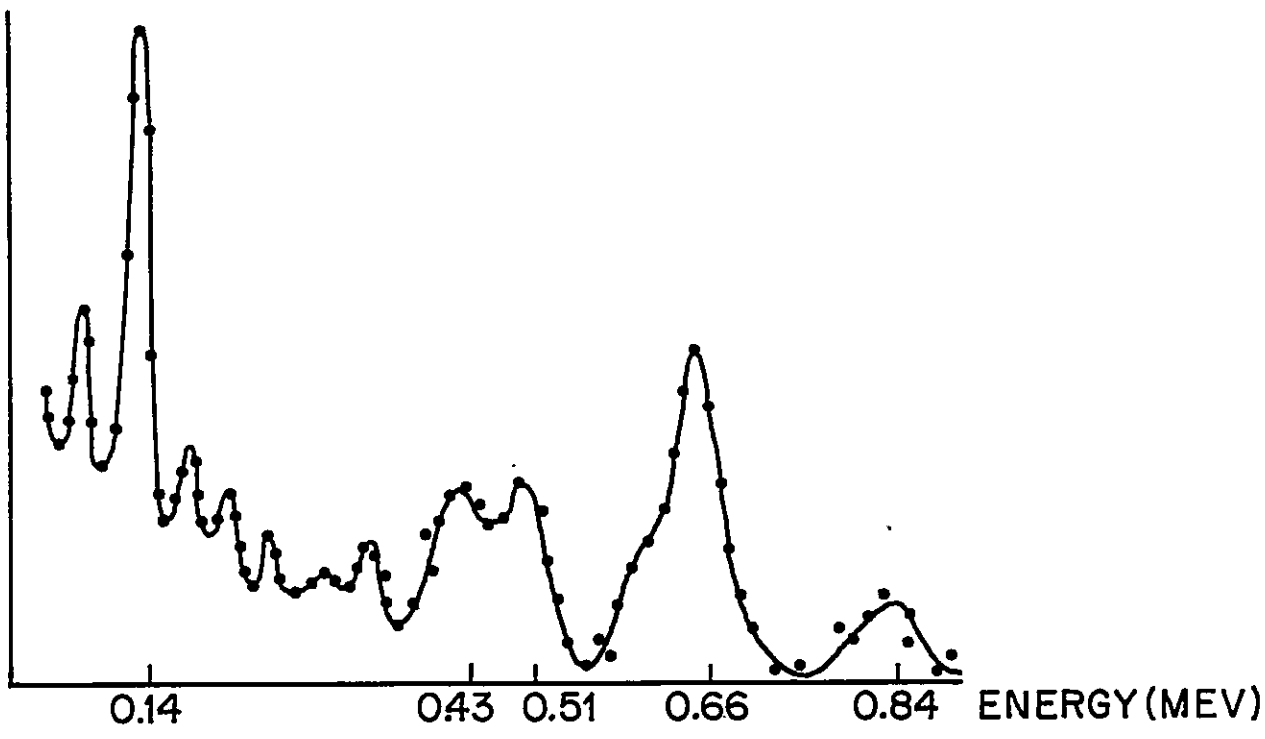


Fig. 2. (Noshkin) Gamma spectrum of air filter sample 1e collected 12-16 April 1965.

Gamma spectra of over-ocean aerosol samples: lower curve from April 1965 (fallout isotope only Mn 54, Cs 137 and Ce 144); upper curve from June 1965--after the Chinese atmospheric test in May--(note increase in fallout contribution and appearance of new peak at 0.77 Mev from Zr-Nb 95.

RADIOELEMENT STUDIES IN THE OCEANS

V. T. Bowen, V. E. Noshkin, G. Thompson and H. D. Livingston

Our overall program is designed to use measurements of radionuclides introduced into the marine environment from atmospheric nuclear testing, supplemented by measurement of a few naturally produced radionuclides, and of the concentrations, in various phases of the environment, of stable elements pertinent to the arguments being developed, to infer the processes, and their rates, responsible for movement of these and related elements in the hydrosphere. This design requires analyses of samples of atmospheric aerosols, of sea water, and of marine organisms, sediments, suspensoids, and rocks.

Radionuclides in Over-Ocean Aerosols

V. E. Noshkin

Early Russian studies of over-ocean aerosols resulted in reports that these contained up to four times the over-land concentrations of fallout radioisotopes, for equal air volumes and within comparable 10° latitudinal bands. Since 1964 we have been making aerosol collections to check this and to elucidate the over-ocean patterns of isotope concentrations and possibilities of element fractionation.

Integrated over the latitudinal band 0° to 40°N, aerosols collected from surface air over the Atlantic Ocean during parts of 1964, 1965 and 1966 have shown fallout radioisotope concentrations equal to or slightly less than the averages for over-land concentrations. Within the periods when our ships were sampling at sea, we obtained data from only four complete months; these sets of data are directly comparable to the over-land data, which is presented always as the result of 30-day collecting periods. For the 10° latitudinal bands, month to month comparisons show significant differences in fallout isotope concentrations over-ocean from those over-land. Less fallout was found in the 20° - 30°N latitudinal band, but a correspondingly higher concentration in the 0° to 10°N band. When the concentration of over-ocean Cs137 was plotted against mid-point position during sampling periods, each north-south traverse showed distinct inflections, which suggest the positions of the equatorial convergence zone. Fresh debris from the May 1965 test by the Chinese was observed sooner over equatorial waters than over comparable land stations. This suggests more rapid purging of debris from tropospheric air over-ocean than over-land at these latitudes.

No fractionation was observed between Cs137 and Ce144, nor, within the errors involved, between Sb125, Ru106 and Mn54, in over-land and over-ocean aerosols as a function of latitude. The decreases in isotope ratios with time correspond to those observed over-land or in high altitude samples over the same time period. Be7/Cs137 ratios were in general higher with low concentrations of Cs137 and lower with high concentrations. Be7 is produced from the interaction of cosmic particles on low atomic weight isotopes present in the atmosphere while Cs137 is derived from atomic testing. The reasons for the concentration variations are not clearly understood. Analysis of aerosols collected in 1967 have been complicated by the presence of short-lived activity from both French and Chinese tests carried out in the atmosphere late in 1966. Preliminary data indicate there was more transfer of debris across the equator in tropospheric air masses over the ocean.

Rainwater has been collected to provide data collateral to that from aerosol samples during several cruises. Procedures are being devised for chlorinity, stable isotope and radioisotope measurements on these small samples. The correlation between rainfall over-ocean and fission products in marine aerosols is being investigated.

Work on vertical distribution of fallout isotopes in both marine and fresh water sediments is being continued. A newly-devised large-cross-section sediment corer (20 cm diameter) was successful in obtaining several cores in Crater Lake, Oregon, this year. This work is part of a program (sponsored by the Health and Safety Laboratories, U. S. Atomic Energy Commission) to compare the fallout collection efficiency of a large body of water and that of the surrounding land area. Analysis for fission products in the top centimeters from four cores by gamma ray spectroscopy has shown the concentrations present to be below detection limits. Radiochemical techniques will be employed to determine the levels present.

RADIONUCLIDES IN SEA WATER

V. T. Bowen, V. E. Noshkin, T. T. Sugihara

We have continued our program of analyses of both surface and deep ocean water for strontium 90, cerium 144 and promethium 147, looking for cesium 137 in a few samples as well. Through the cooperation of the Health and Safety Laboratory, U. S. Atomic Energy Commission, our own radioanalytical efforts have been supplemented both by a modest number of analyses at the Health and Safety Laboratory and by a large number done, under contract, by suitably qualified industrial laboratories. The mass of data so collected is currently being summarized as a part of the National Academy of Sciences, Committee on Oceanography, Panel on Radioactivity in the Marine Environment's forthcoming publication on this subject. This summarization is including all other published and a great amount of unpublished data; one of the most gratifying aspects of the exercise so far has been the surprisingly extensive agreement among analysts in Europe, South Africa and this country. The magnitude of our contribution is evident in the final summary: when the Atlantic Surface Water data are assembled by 10° latitudinal bands averaged annually, of 84 data points since 1954, 59 depend wholly, and 11 more partly on Woods Hole Oceanographic Institutions samples.

The surface-water data, presented as outlined above, are strongly indicative of the extent to which downward movement, by mixing or convection, controls surface concentrations of such tracers as Sr 90: from 1961 to 1964 concentrations increased three-fold or more in latitudinal bands north of 30°N, and about two fold in bands from 30°N to 10°S (south of 10°S data are inadequate), compared to an increase of 2.5-fold at New York City; by 1967, delivery rates having fallen precipitously in 1965, 1966 and 1967, concentrations in the bands from 30°N to 10°N and from 40°N to 70°N had fallen to less than the 1962 values, only in the band 30° - 40°N still lying well above the 1962 value. During this period when all surface concentrations north of 10°N showed steady diminution, no southerly areas showed increases, indicating that the Sr90 lost from north of 10°N had nowhere to go but deeper in the water column. Analysis of the very low concentrations of Sr90 in deep water (below about 1000 m) is still difficult, and some dispute persists about the data. Careful summarization of the vertical profiles of Sr90 concentration from surface to 700 m does not show any increase in these easily-measurable concentrations, expressed as percent of the surface concentration at the time of sampling, during the period of diminishing surface values; this appears to leave the Sr90 leaving the surface water nowhere to go but into deep water masses, and so, by inference, to confirm our agreement with Russian and Danish analysts that many samples of sea water from 1000 m to 5000 m depth in the Atlantic have small but significant Sr90 concentrations. The implications of this body of data for ocean current description are still being examined.

Analysis of Sea Water

V. T. Bowen, V. E. Noshkin, O. T. Hogdahl

We have continued to concern ourselves with the concentrations in sea water of some stable elements relevant to our fallout nuclide studies; the major effort has been devoted to the stable lanthanides, a cooperative program with the Central Institute for Industrial Research, Oslo, Norway, and the minor one to analysis of fluoride.

The lanthanide work has been quite exciting and is causing a complete rewriting--now in progress--of our ideas of the marine geochemistry of this interesting group of elements. Briefly, we found that the North Atlantic Deep Water from 16°N to the equator and in the western basin to about 4000 m, in the eastern all the way to the bottom, is characterized by a uniform profile of relative concentrations of the 13 lanthanides plus yttrium; the Antarctic Intermediate Water and Antarctic Bottom Water showed profiles significantly different from that of the North Atlantic Deep Water, and also different from each other. Other water masses are also proving to show characteristic and different profiles, and only that of the very shallow Barents Sea resembles that of modern marine sediments--which we have found to be statistically identical to the "average marine shale" profile (Haskins, *et al.*). Such broad uniformities of relative concentration profiles differing from that of bottom sediments, we take to preclude the possibility that the very short oceanic "residence times" (less than 200 y for all lanthanides, and less than 100 y. for some) conventionally calculated by Goldberg can apply to the open ocean; they seem equally irreconcilable with Goldberg's hypothesis that the omnipresent cerium deficiency in sea water--which our data fully confirm--is attributable to a selective removal at the sea bottom on to manganiferous nodules and crusts. Further sampling and analyses are now in progress but we favor, from the data now in hand, the hypothesis that

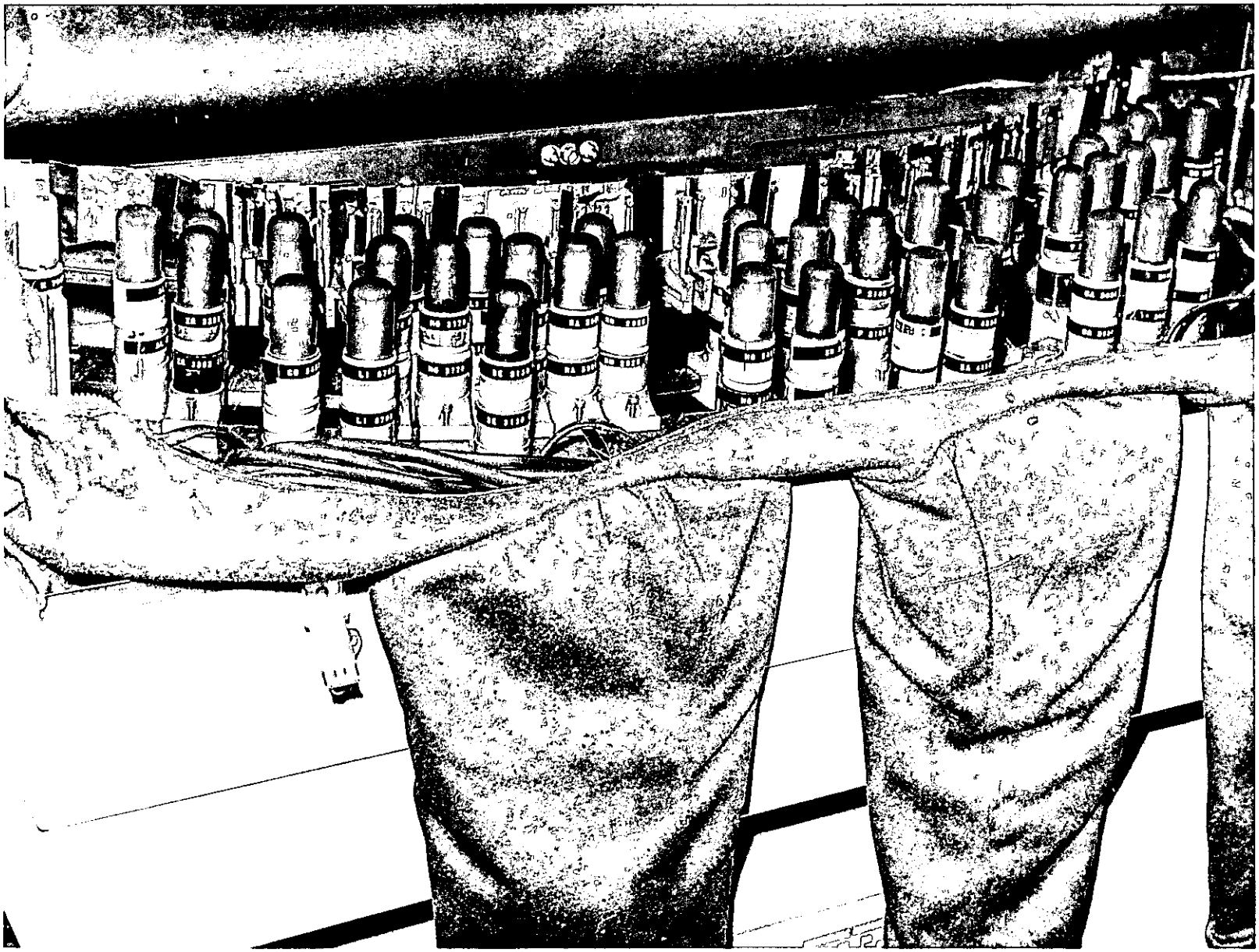


Fig. 1. (Thompson) Internal view of the Direct-Reading Spectrometer showing exit-slits on focal curve and photomultiplier tubes.

sea water lanthanide concentrations are controlled by solubilization of small fractions of the lanthanides in continental run-off by exometabolite complexers of the plankton populations characteristic of the surface waters which sink to form the various deep-water masses so far analysed. This hypothesis has the advantage of being consistent with the data, and, we believe, experimentally testable.

Fluoride is a major component of the minor element spectrum of sea water; the strength of its inorganic combinations with iron, with silicon, with boron and with the lanthanides has been variously suggested as controlling some aspects of the geochemistry of these important elements. Development of the fluoride specific ion electrode made it possible to examine two aspects of the marine chemistry of fluoride: does it show the ion-activity expected from its concentration; and does it show major concentration variation with depth? Vertical profiles show variations in fluoride concentration by as much as minus 20%, the maximum typically being found at the surface. Even in enclosed sediment-pond basins about the Mid-Atlantic Ridge, where bottom-water-silicate concentrations may reach several fold those of the intermediate water, no marked effect on fluoride concentration was found.

Elemental Analyses of Plankton and Sediments

Geoffrey Thompson

Emission Spectrometry:

In 1967 the emission spectrographic laboratory functioned more or less routinely. The vicissitudes of the previous year have been overcome; temperature and humidity control now function reasonably well. The dc arc analytical technique developed during the previous year is now in routine operation. The computer program, also developed last year for processing data from the direct-reading emission spectrometer, has proved successful.

Studies of the elemental composition of marine plankton species, previously begun by colleagues at Manchester University, England (Nicholls, Curl and Bowen 1959), were continued in this laboratory. Forty-four specimens were analysed to give data on 26 elements. Among these specimens were mixed collections of phytoplankton and single-species samples representing the Phaeophyceae (*Sargassum*), the coelenterates, ctenophores, molluscs, Crustacea, tunicates and chaetognaths. For many species and many elements this is the first data available.

Trace element studies were made on basalts and their metamorphosed equivalents from the Mid-Atlantic Ridge about 22°N to supplement previous petrological studies. Other igneous rocks analysed include ultrabasic speciments from the St. Paul's Rocks mantle-derived intrusion. Also completed this year were analyses of an alkali basalt dredged from the flanks of the St. Paul's massif; this was of importance being the first report of a high nepheline-normative basalt dredged from depth and not associated with a large tholeiitic volcanic pile. Trace element studies of pelagic sediments are also continuing, particularly from sedimentary ponds on the flanks of the ridge at about 22°N.

Mid-Atlantic Ridge Studies:

Comparative geological studies of the Mid-Atlantic Ridge were continued during the *Atlantis II* Cruise 32 in June-July of 1967. A section of the Ridge at about 43°N was surveyed in detail and a large collection of rocks and sediments obtained. Geophysical investigations included magnetic and heat-flow measurements. The magnetic, topographic and geological data indicate a marked and sudden change in the normal Ridge structure in this area. Reports of this work are being prepared jointly within the Institution with Dr. V.T. Bowen, Dr. J.D. Phillips and Dr. R.P. Von Herzen, and with our colleagues at the U.S. National Museum, Dr. R. Cifelli and Dr. W.G. Melson.

Lanthanide Geochemistry

H.D. Livingston

The potential of lithium-drifted germanium detectors for minimizing chemical processing in the determination of lanthanide elements in modern marine corals by neutron activation has been explored. The high resolution obtainable with these detectors permits the measurement of many more components of a complex mixture

of gamma rays than is possible using NaI(Tl) spectrometry. The comparison of the lanthanide patterns in the corals with the surrounding water patterns should have geochemical significance. If essential similarity exists, then lanthanide pattern determinations in fossil corals should serve as a paleontological indicator of the water lanthanide pattern at the time of coral formation. If significant differences exist, the uptake by corals may be one factor contributing to control of the sea water lanthanide pattern. Much of the experience gained with these coral measurements is relevant to the analytical problems presented in the elemental analysis, by activation of other biological or geological marine material and will facilitate future work in these areas. As a by-product of the lanthanide activations, data are also obtainable, with little added effort, on the concentrations of several other trace elements.

Preliminary data have been obtained for La, Ce, Eu, Tb, Yb and Lu among the lanthanides and for Sc, Fe, Co, Zn, Cr and U. Large differences in trace elements and lanthanide content were found between shallow, open-ocean corals and a typical nearshore species. Tracer experiments and activation analysis of residue remaining after dissolution of the carbonate matrix of the coral suggested that these differences were related to different trace element levels at the external surface of the coral rather than inside the carbonate matrix.

Non-destructive analysis (by direct gamma ray spectrometry on the intact sample after neutron activation) is possible for Ce, Eu, Sc, Fe, Co, Zn, Cr and U at the levels found in corals so far examined. For analysis of sufficient elements to define the lanthanide distribution pattern, it was necessary chemically to separate the activated lanthanides as a group from the irradiated material before gamma spectrometric analysis. This separation included an anion exchange removal of ^{239}Np and ^{47}Sc from the lanthanide group. Activation of U and Ca in the corals produced these nuclides as decay products, and their presence interfered with the determination of several lanthanides.

Fission of the U in the coral also occurs during activation and the extent to which the lanthanide fission products interfered with the analyses was evaluated. The interference was particularly significant for Ce, and to a lesser extent for Sm and La. Since lanthanide content of the corals varied more widely than the U content, the fission interference was more serious in corals with the lowest total lanthanide content. Procedures are being evaluated for precise measurement of the fission-product contributions in each analysis, so that realistic blanks can be subtracted for each sample.

Relevant Geological Studies

V.T. Bowen and G. Thompson

We have continued during the year to work up data from our detailed surveys of the Mid-Atlantic Ridge at about 22°N, about the Vema Fracture Zone, about St. Paul's Rocks and about the Romanche Trench; in July, with some cooperation from Dr. J.D. Phillips and Dr. R.P. Von Herzen, we made another such detailed survey at about 43°N. This promises to have been a most fortunate choice of location; the survey included both a segment of "normal Ridge" ((1) with central valley; (2) relief linear adjacent to the valley, the linearity diminishing with distance from the central valley; (3) magnetic linearity well (developed); (4) only reasonably fresh basalt recovered from the slopes; and (5) heat flow in the central valley little higher than in valleys east or west of the Ridge axis) and a section of "disturbed Ridge" ((1) central valley continuous but distorted; (2) adjacent relief east-west linear rather than north-south; (3) magnetic linearity not apparent; (4) only serpentinized-peridotite recovered from the slopes; (5) heat flow unusually high in the central valley; (6) bathmetric evidence that the whole plane or Ridge--over 3° longitude or more--had been tilted) but without the marked lateral displacement of the Ridge (axis) characteristic of fracture zones. Study of these data and preparation of preliminary reports are proceeding.

The detailed survey of the Vema Fraction Zone (near 11°N) has shown that the sediment fill of the Fracture Zone Valley must have accumulated over a long period of seismic inactivity, indicating an interruption of some millions of years in sea-floor spreading at this point on the Ridge. The southern wall of the Fracture Zone was found to be a very high, steep, narrow wall of rock, extending more than 4° of longitude from east to west and probably an unlifted slice of crust; both serpentinized peridotite and basalt have been recovered from this wall, the basalt being from the uppermost slopes.

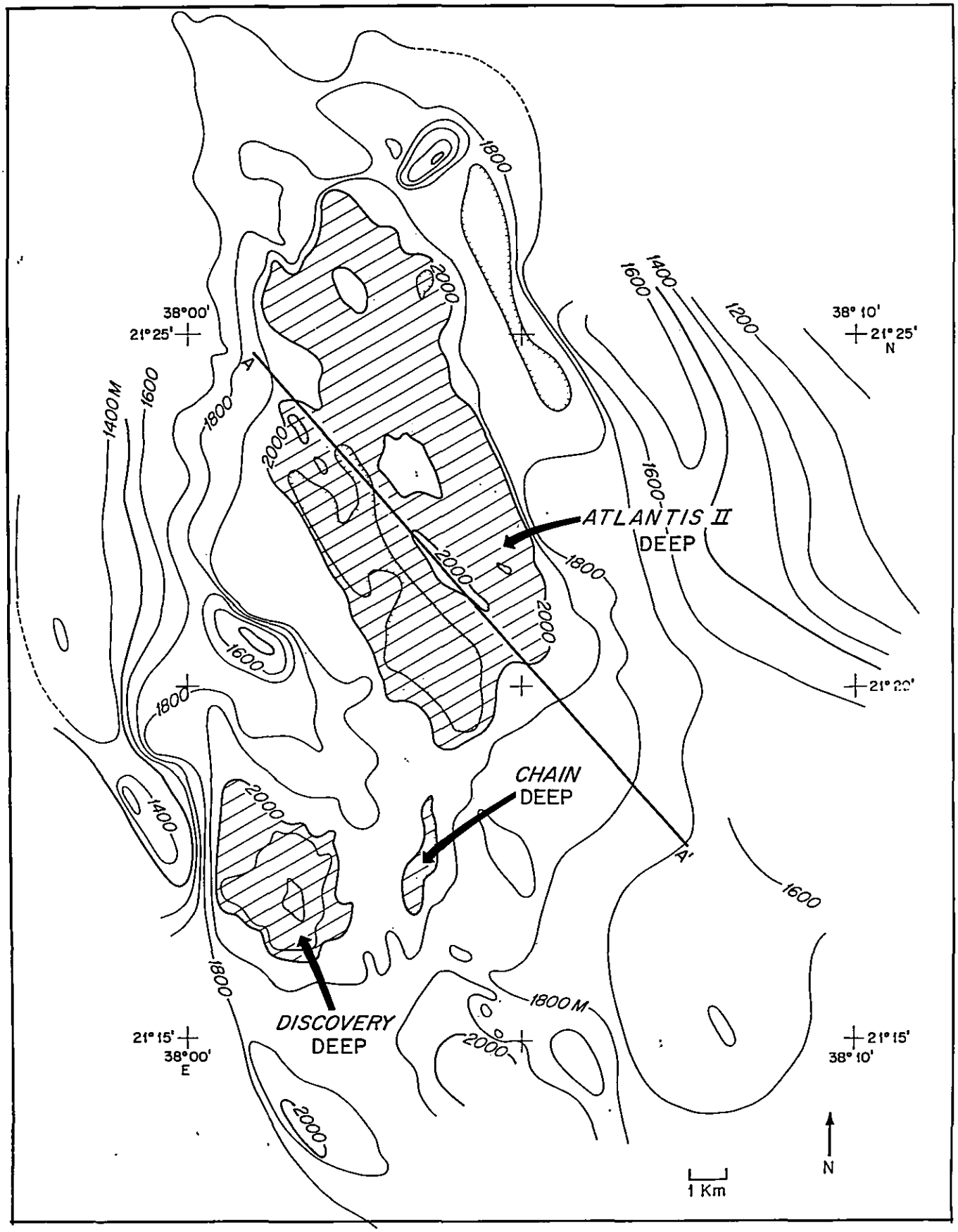


Fig. 1. (Hunt) Bathymetry of the hot-brine region in the Red Sea. Hot saline water occurs in the hatched areas. Depth contours (m) corrected for sound velocity using Matthew's tables. No correction has been applied for the increase in sound velocity in the hot brines.

Reexamination in some detail of the Romanche Trench and Fracture Zone has shown the trench itself to be somewhat less complicated bathymetrically than was inferred by Heezen, but that the fracture valley, expecially that part east of the trench is much more complex, distorted, and cannot serve as a sediment-channel to the trench itself. Mr. P.L. Sachs is cooperating with us in this study. An extremely complex suite of rocks was dredged from the walls of both trench and fracture valley; study of these, and of the sediments in cores and dredges is continuing.

A recurring feature of our dredging about the Ridge is the recovery of lithified carbonate sediments. These range widely in chemistry, age, and degree of lithification, from loosely consolidated foraminiferal or coccolithophorid oozes, to well-lithified but no recrystallized oozes, to tuffaceous limestones rather low in carbonate, to fully recrystallized calcite of very high density, and to massive dolomite (so far recovered both from St. Paul's Rocks massif, and from about 43°N); ages range from Recent to early Eocene. No correlation is discernible between age, depth of occurrence, or chemical composition, and degree of lithification; the frequency of close spatial association of rocks of obviously very different histories of lithification emphasizes that carbonate lithification on the sea-floor while obviously very wide-spread, must depend on very local variations in the chemical and physical environment.

These studies are being made in cooperation with such colleagues as Dr. Tj. H. van Andel at the Scripps Institution of Oceanography, and Dr. R. Cifelli and Dr. W.G. Melson at the U.S. National Museum Smithsonian Institution.

Plankton Distribution Studies

V.T. Bowen, R. Cifelli, B. Schreiber

We have continued to make extensive collections, using uniform towing procedures and fine-meshed nets, of open-ocean plankton, most especially for study of the distributions of Foraminifera, Radiolaria and Acantharia. In the past year about 200 tows were made, from about 40°N to about 35°S; examination of these samples is still proceeding. Data from earlier cruises confirm that, at least on the space-scale represented by an oblique plankton tow, there is no evidence for competitive displacement of either other group by Foraminifera or Radiolaria or Acantharia. In general, conditions favoring increased abundance of one group favor increase of the others as well. Foraminifera data in the North Atlantic area of "Worthington's Gyre" or of the northeastward extension of the Gulf Stream do not permit an unequivocal choice between the two suggested current patterns; a significant input, at the eastern side of the gyre, of water carrying southerly populations of "warm-water" Formaminifera, is, however, strongly suggested. Further sampling in this area was conducted last July to examine in more detail this northward spread.

Correlation of specific Foraminifera species, or of details of population patterns with the current system in the equatorial Atlantic is proving both profitable and complex. Some peculiarities of Foraminifera populations in equatorial sediments--studied first-- are proving characteristic of the plankton populations, especially in the Equatorial Undercurrent. There is some hope of using this pattern to explore sediment columns north or south of the equator for past deviations of the Undercurrent from its present position.

GEOCHEMICAL STUDY OF RED SEA MINERAL DEPOSITS

John M. Hunt

A major part of the geochemical program was concerned with the analysis of samples obtained on the Red Sea cruise of *Chain* in the fall of 1966. Data are reported by Ross, Deuser, Bischoff, Ku and Brewer. Complete reports by scientists at Woods Hole and other Institutions are being compiled in a book of the Red Sea to be published by Springer-Verlag.

A bathymetric chart of the area (Fig. 1) was prepared from over 60 traverses of the deeps, and used to guide the research program. Emphasis was on the *Atlantis II* Deep which is the probable source of the hot brines and heavy metals. This hole contained several minerals such as an iron-montmorillonite and hematite, which are not found in the other deeps (Bischoff).

Carbon and oxygen isotope studies of the microfossils in the hot holes and south of the area were particularly interesting in showing the effects of the high temperature brine on the isotope ratios. Also, when combined with C-14 dates, it was possible to follow three cyclic changes in ratios with depth. These are apparently related to glacial periods (Deuser).

Analyses of the heavy metals in the sediments showed wide variations with some samples containing 3% of copper and of zinc on a dry weight basis. F.T. Manheim of the U.S. Geological Survey made a preliminary estimate of the value of the copper, zinc, silver and gold in only 10 meters of the *Atlantis II* deposits. He showed that 130 million tons of the dry, salt-free ore has a value of 1.5 billion dollars. The economics of recovering such ores is unknown, however, because there are no mining procedures for handling such watery sediments of great depths. Each cubic meter of bulk mud in the first 10 meters contains only 250 kg of salt-free dry solids.

MINERAL GENESIS AND MINERAL-SEA WATER INTERACTIONS

James L. Bischoff

Kinetics of Calcite Nucleation:

A study of Mg^{++} ion effects on calcite nucleation was part of a general project completed on the effects of various sea water components on crystallization rates of calcite and aragonite. Previous work had shown that aragonite predominance in the marine environment was somehow due to the presence of the Mg^{++} ion.

The kinetics of the aragonite-calcite transformation in dilute $MgCl_2$ solutions saturated with aragonite were examined. Mg^{++} ion inhibits the formation of calcite with the time interval between aragonite equilibration and first observable calcite directly proportional to the Mg^{++} concentration which decreased linearly with time to below 2 ppm. Normal rates of calcite crystallization then took place.

The inferred inhibition process is that the strongly hydrated Mg^{++} ions are absorbed on growth sites of calcite nuclei and block further growth. As a result, both the Mg^{++} ion and the nucleus are removed from the reaction. Extrapolation to sea water concentrations of Mg^{++} indicates infinitely slow calcite crystallization rates, and accounts for the predominance of aragonite in marine deposits.

Interstitial Water Studies, Gulf of Mexico Slope Sediments:

In cooperation with F.T. Manheim, the first stages of interstitial water studies of the sediments from the Gulf of Mexico slope have been completed. Specially collected and sealed sediment samples were obtained through the courtesy of Shell Oil Company, which is conducting a general geological and geophysical study of the Gulf slope, including the drilling of a series of 1000 foot holes from the drilling ship *Eureka*. Water squeezed from the samples from five holes (all within Pleistocene clayey sediments) were analyzed for Cl^-, pH, buffer capacity, and major ions (Na, K, Mg, Ca, SO_4, and Sr).

Data show that, for the two holes drilled above inferred salt diapirs Cl^- increased continuously with depth. Projection of Cl^- to estimated depth of cap rock shows a close approach to NaCl saturation. The remaining three holes showed no such increase. Thus, dissolved salts seem to be streaming off the dome and diffusing through clayey sediments with a facility not previously appreciated. Increase of the K/Cl ratio on one of the salt diapir holes suggests the presence of sylvite (KCl) in the cap rock, an occurrence not reported for the onshore cap rocks in the area. For all the holes a general inverse relation was noted between SO_4 concentration and buffer capacity, indicating the activity of sulfate-reducing bacteria. The preliminary work is now in preparation for publication and work on additional holes is in progress.

Mineralogy and Geochemistry of Red Sea Brine Deposits

Nine cores taken from the *Atlantis II* and *Discovery* deeps of the Red Sea brine area were examined by microscopic and X-ray diffraction techniques. The deposits consist of precipitates from the brine and detrital-pelagic debris. The interstitial brine content ranges from 60 weight percent in the *Discovery* Deep to 95 weight percent in the deepest part of the *Atlantis II* Deep. The latter is the suspected source of brine exhalation

The precipitate, generally ranging in grain size from 2 to 62 microns, is characterized by the following major mineral suites: (1) hydroxide (geothite, lepidocrocite, limonite), (2) silicate (Fe^{++} rich clay, believed to be

an undescribed mineral species), (3) *sulfide* (sphalerite, pyrite, chalcopyrite), (4) *carbonate* (rhodocroiste-siderite), and (5) *oxide* (manganite, todorokite, hematite). The silicate and sulfide suites are most abundant in the deeper areas of the *Atlantis II* Deep and decrease toward the shallower areas. The hydroxide suite has an opposite pattern.

Two dominant processes of mineral precipitation are suggested, (1) cooling of subterranean brine as it reaches the bottom of the *Atlantis II* Deep (sulfides and silicates), and (2) mixing of the brine and overlying sea water with resultant oxidation of Fe and Mn, and precipitation as oxides and hydroxides.

The final stage of the geochemical work is spectrochemical analysis of the samples, which is now underway.

URANIUM SERIES DISEQUILIBRIUM

Teh-Lung Ku

An alpha-counting laboratory has been set up for the study of the longer-lived nuclides in the naturally occurring radioactive decay series. The laboratory has a 512-channel analyzer with readout and spectrum stripping modules for measuring U^{238}, U^{234}, Th^{232}, Th^{228} and Po^{210}, and a low alpha background flow-type proportional counter for measuring Pa^{231}.

Th^{230} and Pa^{231} are rapidly removed from the solution and are found greatly concentrated relative to the parent uranium in deep-sea sediments. The evidence for varying ocean climates recorded in the sediments can thus be dated by the amount of unsupported Th^{230} and Pa^{231} remaining in various layers of sediment. On the other hand, the uranium, found in sea water practically free of its daughter products, is commonly incorporated in carbonate secreting organisms and in inorganically precipitated carbonates. These fossil carbonates are then dated by the extent to which Th^{230} and Pa^{231} have returned to equilibrium.

A tentative time scale for sea-level fluctuation and climatic variation on the earth in the last 200,000 years has been obtained from Th^{230}/U^{234} and Pa^{231}/U^{235} dates on fossil corals from the elevated reef terraces of Barbados Island, West Indies. Current-geochronological investigations on sediment cores taken from the Red Sea are expected to yield valuable information regarding the Quaternary history of the area. In view of the importance of the two radium isotopes, Ra^{226} and Ra^{228}, as oceanographic tracers, development of techniques for solid source radium spectrometry will be sought.

MARINE ORGANIC CHEMISTRY

Max Blumer

Our research continues in the following areas:

(1) Definition of the sources and description of the types of organic compounds in the sea and in marine sediments; (2) search for regional differences in the chemistry of marine, especially planktonic, organisms; use of such differences as markers of marine processes; (3) study of the dispersal of organic compounds through the marine food chain and application of this to the tracing of dynamic processes in the food chain; (4) study of the dispersal of organic compounds through the sea, and application of this to the tracing of the movement of water masses; (5) study of the incorporation of biochemical products into marine sediments; (6) study of the long-term fate of organic compounds in marine sediments and elucidation of the type and intensity of organic reactions in the subsurface.

Our research in these areas has concentrated on selected hydrocarbons and lipids, both because of their great structural variety and their relatively long half-lives. In cooperation with investigators from the National Institutes of Health, we have studied the phytol metabolism in *Calanus*. This terpenoid alcohol is converted either by the crustacean or its intestinal bacteria into phytanic acid. Subsequently, pristane is formed by decarboxylation of the acid.

Phytanic acid, pristanic acid, and 4,8,12-trimethyltridecanoic acid have been isolated from three recent marine sediments. The ratio of palmitic to pristanic acid is similar to that encountered in typical marine lipids. This suggests a biochemical origin of these sedimentary acids; phytol is their presumed biochemical precursor. Other isoprenoid acids between C_{11} and C_{22} which are common in ancient sediments have not been found. They are probably geochemical products formed slowly and at a greater depth.

The presence in Recent sediments of singly branched (iso- and anteiso-) fatty acids is of considerable interest because of their possible role of precursors of the branched paraffins in ancient sediments and crude petroleum. Also, these acids are commonly formed by bacteria and may well provide a marker for the bacterial contribution to the sedimentary lipids.

Earlier investigators had isolated but only partly resolved O_{12}-O_{18} iso and anteiso acids. With improved gas chromatographic substrates we now have resolved the iso and anteiso acids from C_9 to C_{21} in three not previously studied recent environments.

A simple and rapid survey technique has been developed for the analysis of the hydrocarbons of marine plankton and fishes. This has been applied to a preliminary survey of the hydrocarbons in mixed zooplankton samples collected from Cape Cod to about 45° West. The samples taken nearshore show the typical hydrocarbon distribution of *Calanus*: a drastic change with a decrease of pristane and a relative increase of olefinic hydrocarbons marks the transition to other faunas. Some of this work was done on well preserved but not recent collections. Fresh material for such a survey should now be collected.

Some attention has been paid to the presence in marine animals of unknown fatty acids occurring in minor concentrations. Several new homologous series of saturated and olefinic branched fatty acids have now been discovered in the lipids of copepods, of cod, basking sharks and tuna. The structures of these acids are presently being investigated. Again this calls our attention to how cursory our knowledge of the chemistry of marine organisms still is. It is mandatory for our proposed studies of the organic chemistry of sea water to know more about the potential sources of such compounds in marine organisms.

Much of our work, especially on the central problem of the chemistry and fate of organic compounds dissolved in the sea, has been slowed down by the extreme difficulties involved in isolating sufficient material for the conventional methods of organic structural analysis. We have been fortunate to obtain and install a Consolidated Electrodynamics Model 21-104 mass spectrometer. Operating experience with this instrument has now been gained and the inlet systems have been modified to permit the contamination-free handling of very small samples. The spectrometer has been interfaced with a gas chromatograph. A carrier gas separator has been designed from readily available parts. Surface area, dead volume, peak delay and peak broadening have been minimized. Isolation or simultaneous operation of the chromatograph and spectrometer is possible and chromatographic efficiency is unaffected in either operating mode.

The combination of gas chromatograph and mass spectrometer is one of the most powerful tools of organic chemistry. Complex samples are separated into their components. These are analyzed without further processing and structural information, often sufficient for complete identification, is obtained instantaneously. We expect to apply this to the identification of organic compounds isolated from organisms, sediments and from the sea water.

MOLECULAR MECHANISMS ON INTERACTIONS BETWEEN OXYGEN CO-ORDINATED METAL POLYHEDRA AND BIOCHEMICAL COMPOUNDS

Egon T. Degens and Johann Matheja

The Role of Phosphates in Biochemical Reactions:

The following information is presented on the structural and functional properties of phosphates in biochemical systems. Phosphates follow four structural formation principles:

(1) linkage of phosphate units via oxygen co-ordinated metal ion polyhedra,
(2) establishment of chains,
(3) cross linkages of chains resulting in corrugated layers, and
(4) cross linkages of layers resulting in distinct three-dimensional molecular networks.

One linkage type does not require nor exclude another linkage type.

On the basis of this concept on the associations of phosphate tetrahedra and metal ion oxygen polyhedra, a revised molecular model for DNA is proposed (Fig. 1). Metal ion oxygen polyhedra excercise control on the slope of the DNA, and thus may introduce the stretching of the polymer chains. This can be considered the ultimate reason

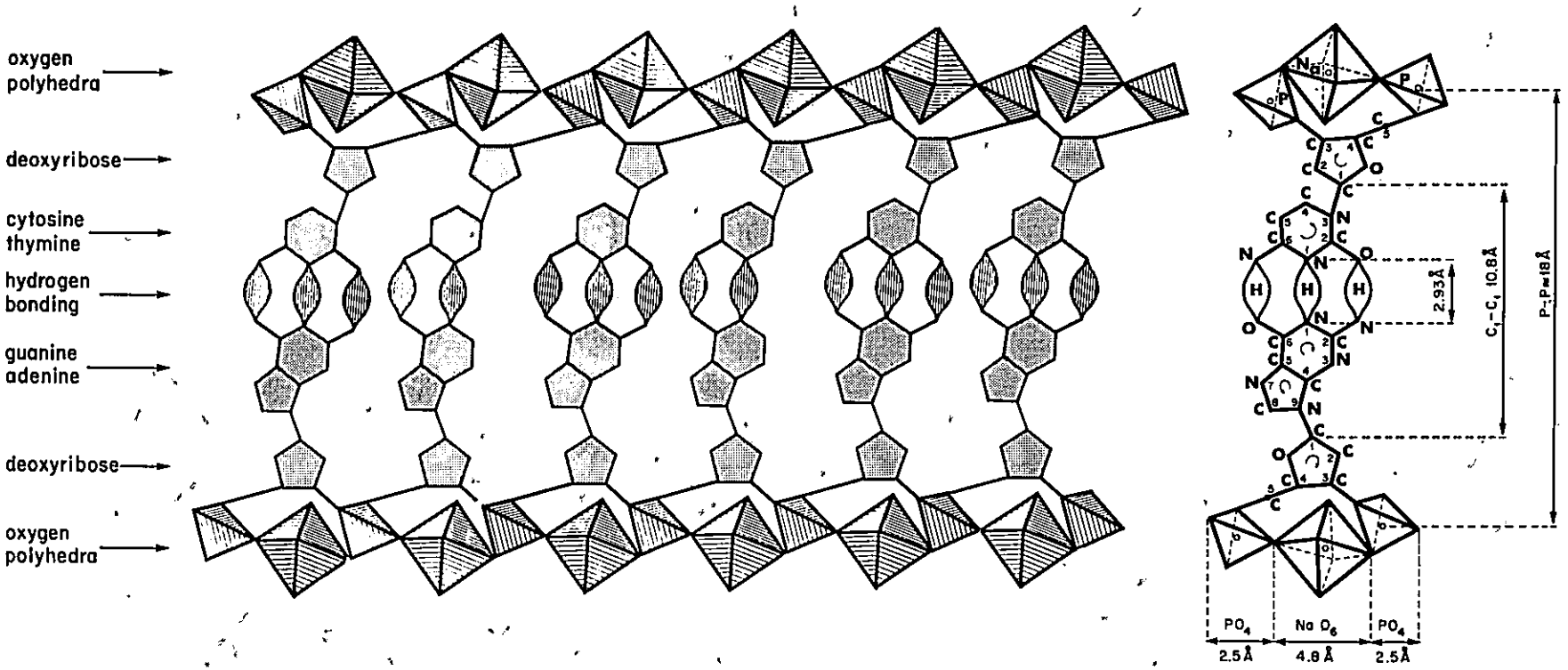


Fig. 1. (Degens and Matheja) Model of DNA (schematic) showing metal co-ordinated phosphate groups. A sodium ion serves as linkage element between two phosphate tetrahedra by establishing an oxygen polyhedron. The intermolecular distance between (a) the hydrogen linked bases of the purines and pyrimidines, and (b) the glycosidic carbons are the most probable ones. In addition, a weak C - H . . . O bonding could exist between thymine and adenine; its consequence for the electron bonding configuration in the aromatics would be considerable (83, 98, 99). It is also interesting to note that extremely short C - O distances (C_3 - O = 2.88 Å; C_2H - O_4 = 2.5 Å) are reported between deoxyribose and phosphate. The authors believe that the ultimate reason for the incorporation of sugars into the nucleic acids is related to the fact that the sugars will supply the oxygen necessary for the construction of the metal ion oxygen polyhedron (C_3 atom).

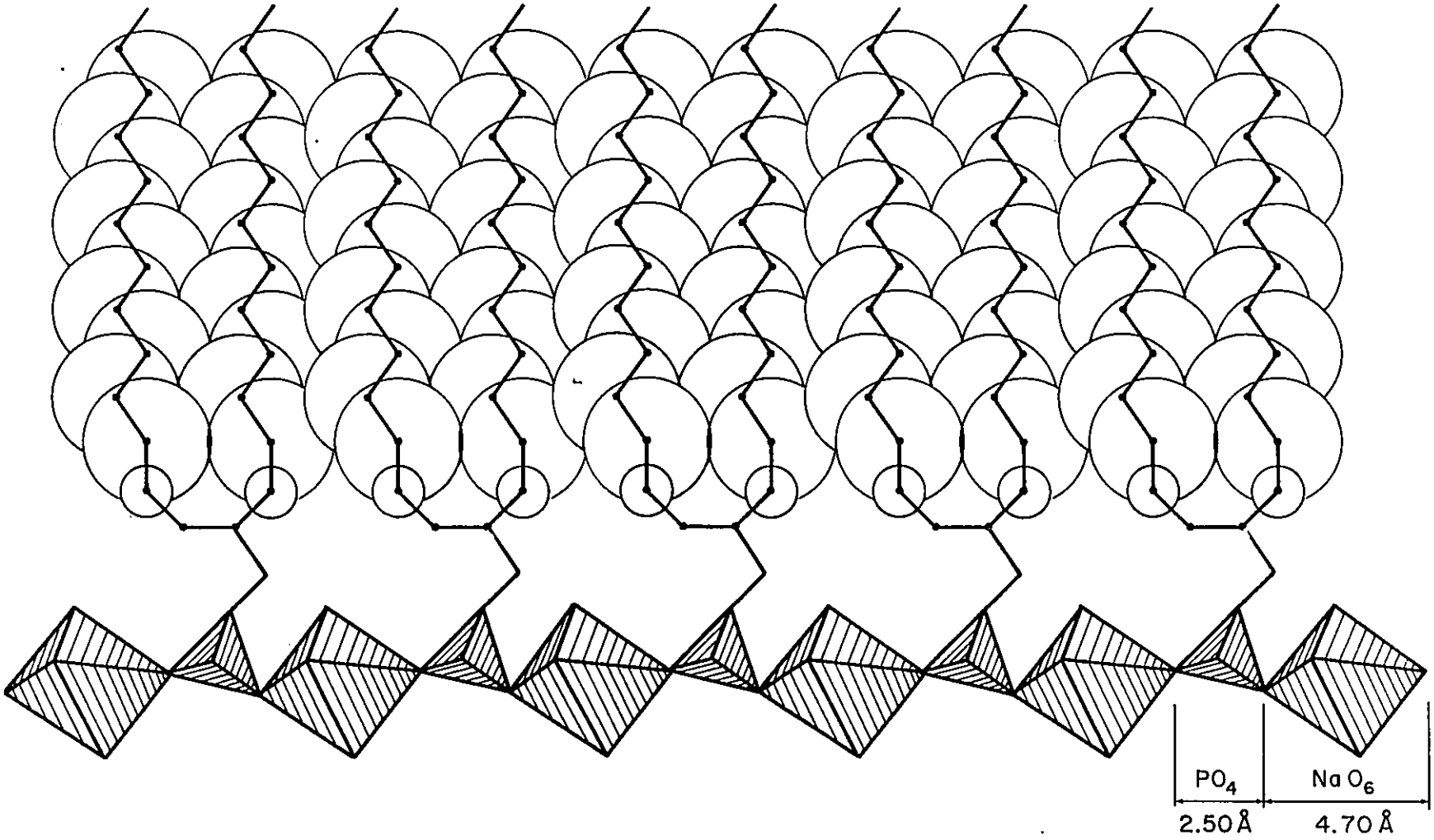


Fig. 2. (Degens and Matheja) Membrane cross-section composed of double chain of lipid-oxygen polyhedra. Glycerol is only schematically represented; the carbonyl groups and the PO_4 residues have been omitted. The molecular dimensions are based on the NaO_6 octahedron. The molecular aggregation, as presented here, results in a corresponding interfacial area fit for both chains concerned. Assuming the surface area of a hydrocarbon chain is identical to the surface area empirically determined for fatty acids (20 $Å^2$ per molecule) (146a, 146b), we obtain the same values for the surface area of a tetrahedron-octahedron unit. The cross-section surface for the minimum six oxygens falls in the range of 33-37.5 $Å^2$ with a most probable value of 35.5 $Å^2$. For metal ions, the mean surface area amounts to 4 $Å^2$. This would add up to a total surface area of 39.5 $Å^2$ for a polyhedron unit, a value which would conform with the surface area of the associated lipids. It is noteworthy, that for sphingomyeline the area, at the time of collapse on the water surface, amounts to 37 $Å^2$ which is identical to the minimum value observed in crystals of hydrocarbons.

why a single-stranded DNA will associate itself readily with another single-stranded DNA resulting in a double helix. In contrast, the coupling of a single-stranded DNA by itself in making a sharp bend (loop) will not take place due to the stabilization of the structure by means of the metal ion oxygen polyhedra backbone. This model also explains the functional properties of the nucleic acids, for instance, the oxide chains and layers will favor proton jumps, and in the presence of a differential potential, they will form proton conduction bands.

The molecular organization, as introduced by the association of metal ion coordination polyhedra with the PO_4 groups, plays also a significant role in membrane dynamics (Fig. 2). Analogous to the ion co-ordination interactions of polyphosphoric acids, the fixation of metal ions at the P-O surface of membranes will result in a distinct molecular geometry as a whole. In this way, the membranes will act as dynamic molecular sieves, whereby the mesh size and the functional characteristics of these molecular sieves is determined by the flexible interplay of metals and the individual phospholipid compounds contained in the membranes.

TP(III-P) is characterized for its ability to form a co-ordination polyhedron with polyvalent cations. In this way it resembles polyphosphates and differs from I-P and II-P. Triphosphate exhibits two significant properties:

(1) terminal chain degradation, i.e. the release of terminal PO_4 groups and formation of PO_3 radicals which is controlled by external electrical forces, and

(2) affinity to all cations by means of metal ion oxygen polyhedra and the establishment of an exchange affinity series for all metal ions.

Origin, Development, and Diagenesis of Biochemical Compounds

Biogeochemists are, *inter alia*, concerned with the origin of proteins and other polymeric building blocks of life during the primordial stage of the earth. From their point of view, it is reasonable to assume that mineral matrices participate in the synthesis of certain organic polymers.

To substantiate this supposition, the behavior of amino acids in presence of mineral templates was investigated. About 60 different minerals, comprising representative members of silicates, oxides, phosphates, carbonates and sulfates were tested for their amino acid sorption characteristics. The selection of minerals was based so as to cover a wide range of crystallographically and chemically different minerals. It could be shown that during reorganization of the mineral phase (e.g. dehydration, recrystallization, and mechanical abrasion) coupling of amino acids occurred resulting in the formation of polypeptides with molecular weights up and exceeding 10,000. Hydrolysis of the polymer fractions separated by molecular sieving techniques resulted in the total recovery of the amino acids originally supplied to the mineral system.

In the light of these results and of previous investigations of the distribution of organic matter in the oceans, fresh-waters, and recent and ancient sediments, a concept on the origin, evolution, and diagenesis of biochemical matter has been developed. This concept illustrates the enormous variety of interactions that may take place in the natural habitat between inorganic and organic phases. The concept further outlines the way at which nucleic acids and the genetic code could possibly have come into existence

Concepts on Abiotic Development of Phospholipid-Membranes, and Origin of Primordial Metabolism

Molecular mechanisms leading to the formation of phospholipids under primordial conditions were investigated. Analogous to amino acids and simple organic acids, a variety of alcohols can be synthesized in atmospheric systems involving electric discharge, the ultraviolet, or ionizing particles. Clay minerals can structurally accommodate preferentially glycol, glycerol and its homologous, relative to other alcohols.

Paraffins must be considered the principal precursor material for fatty acids. The formation of hydrocarbons is hereby related to high-temperature processes, which involve (a) the dissolution of carbon in silicate melts, (b) the production of submicroscopic graphite particles upon cooling, and (c) the hydrogenation of graphite. The required hydrogen is obtained by the hydration of silicates. Fixation of hydrocarbons on silicate surfaces may take place; their subsequent oxidation yields fatty acids.

The formation of lipids from fatty acids and glycerol is intimately connected to the formation of phospholipids. Principally, the phosphate tetrahedra, linked to silicate surfaces, may collect fatty acids and glycerol. This will result in thermodynamically favorable transition structures between the hydrophobic elements

and the ionic silicate network. Molecular processes such as ester formation are the chemical consequences. PO_4 and metal ion oxygen polyhedra will function as catalyzing agents.

The association of phospholipids produces distinct boundary layers at the contact zone between environment and coacervates. Such layers already possess the characteristics of a dynamic membrane system, i.e. flexible molecular sieve properties. This phenomenon is an essential requirement for a primitive metabolism.

The formation of an auto-catalytic phosphorylation cycle is the next step towards the origin of a primordial cell. This metabolic system must have evolved independent of the genetic translation apparatus. The performance of the genetic transcription machinery required the existence of a workable autocatalytic system.

We emphasize: As a consequence of thermodynamic laws and probabilities the development of the phase-separating phospholipid membrances constitutes the physical basis for the development of life and thus represents the primary event. In contrast, metabolism constitutes the chemical basis which for the first time came into existence within the membranes; consequently, it constitutes a secondary event. The codon, placed in third position, eventually established the time-continuity of these fabrics by means of successive reaction cycles and represents a biological phenomenon which falls outside the field of experience of present-day experimental physics.

Concerning the biosynthesis of polysaccharides, proteins, and the nucleic acids, three conditions have to be fulfilled:

(1) activation of the reaction partner,
(2) maximum efficiency and minimum error, and
(3) well-defined control of the reactions in terms of kinetics and transportation mechanism.

All three requirements are most effectively executed by triphosphates. The controlled formation of the reactive PO_3 radical not only activates the reaction partner, but also eliminates by means of the phosphate formation, the OH and O groups from the reaction system and this with extraordinary efficiency and elegance. In biochemical reactions, this role is commonly exercised by ATP.

Molecular Development of Mineralization Templates in Biological Systems

Attention is focused on a novel tool to study evolutionary trends in mineralized organisms. This work considers first the molecular mechanisms leading to the mineralization of organic tissues, and in second place outlines its phylogenetic implications.

Concerning the first question on the calcification mechanisms it can be shown that protein and glycoprotein matrices act as templates for the fixation of anions and cations. Depending on the position of the sorption sites in the three-dimentional proteinaceous network, the nucleation of a mineral phase may take place. In the case of carbonate shells, calcium ions will associate themselves with the COO^- group of aspartic acid and will become co-ordinated with oxygen resulting in a $Ca^{++}O_6$ or a $Ca^{++}O_9$ co-ordination polyhedron. The increase in polyhedra will cause a structural reorganization of the glucosamine and peptide chains. Thus, the metal ion oxygen polyhedra introduce a higher molecular order. The interaction of the polyhedra with the bicarbonate linked to, for instance, lysine or glucosamine by means of hydrogen bridges, results in an exchange of oxygen at the polyhedra, whereby the co-ordination of calcium to oxygen becomes more stable. The availability of oxygen for co-ordination purposes will determine whether calcite ($Ca^{++}O_6$) or aragonite ($Ca^{++}O_9$) will be the end-member of the calcification process. The resulting nucleation processes find their macroscopic expression in the texture and morphology of the calcareous shells.

In the case of phosphate systems, collagen always represents the mineralization template. It is suggested that hydroxyproline or serine are capable of forming phosphodiester bridges. A more comprehensive discussion on molecular mechanisms leading to the formation of bone structures is in preparation.

The phylogeny of calcified tissues is discussed in the second part of this article. It is proposed that the molecular structure of ancestoral shell proteins closely resembles the structure of molluscan periostraca and that the lack of fossilized shell materials in deposits older than 600 million years is a function of the non-existence of mineralized shell materials prior to Cambrian time. During the Precambrian, molluscs exclusively secreted an organic shell. The calcification era started when functional sites in the ancestoral glycoprotein shell-matrix developed by the elimination of certain cross linkages, making, for example, aspartic acid available for the fixation

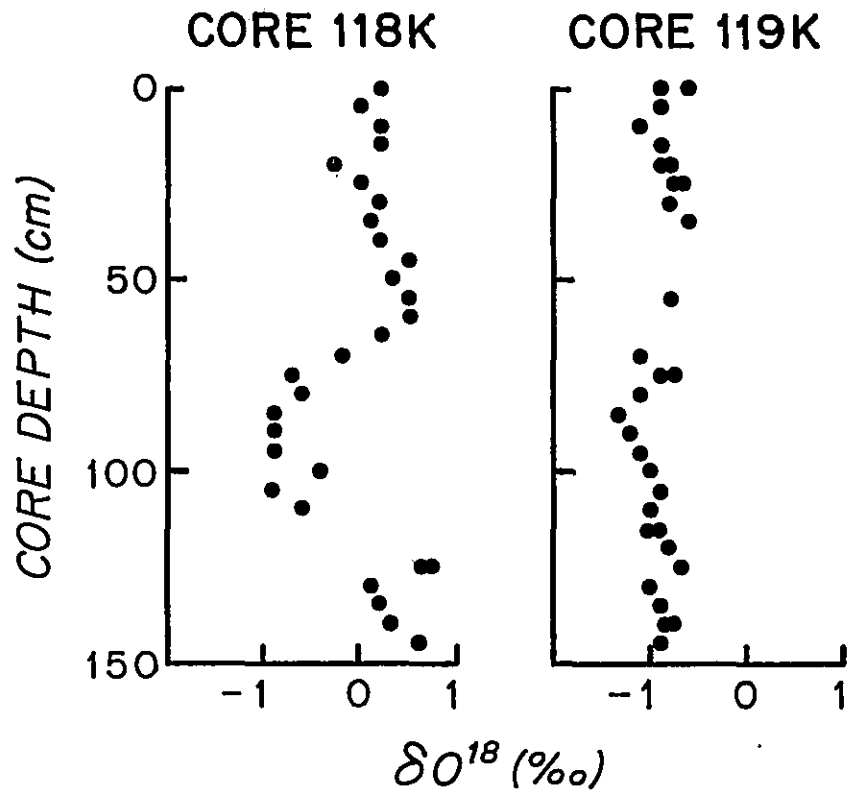


Fig. 1. (Deuser) Reaction with hot brine produced an isotopic shift in Foraminifera tests in the *Discovery* Deep (119K). The two profiles represent sediment accumulated during the last 10,000 years.

of calcium ions. Slight changes in the environmental parameters, such as salinity, pH, temperature, or CO_2 partial pressure, may have actually caused a change in the overall shell secretion pattern of many organisms. In this way, the "population explosion" at the beginning of the Cambrian can reasonably be explained. Namely, organisms started to deposit minerals on an already highly evolved organic tissue. In the course of evolution, organisms progressively modified and improved their shell secretion apparatus, and this phenomenon finds its reflection in the biochemistry of the shell tissue which is species characteristic. In turn, this progressive biochemical change allows the construction of a phylogenetic tree which conforms with the pattern of a phylogenetic tree constructed exclusively on morphological evidences

STABLE ISOTOPE STUDIES

W.G. Deuser

Carbon Isotopes in the Ocean

The equilibrium distribution of the stable isotopes of carbon, C^{12} and C^{13}, between atmospheric carbon dioxide, carbon dioxide dissolved in water, and aqueous bicarbonate was studied through laboratory experiments. Dissolved carbon dioxide was found to be practically identical to atmospheric carbon dioxide. Measurements of the C^{13}/C^{12} fractionation between gaseous carbon dioxide and bicarbonate revealed its magnitude to change from 9.2 to 6.8 parts per thousand over the temperature range 0 to 30°C. These experiments aided in the elucidation of the C^{13}/C^{12} relationships between plankton and sea water. Marine plankton is depleted in C^{13} relative to sea water by one to three per cent. This depletion is due to the photosynthetic process in the phytoplankton. In connection with earlier studies of the carbon isotope content of diatom cultures, grown under a variety of controlled conditions, it could be shown that the extent of the C^{13} depletion in the plankton is determined by the pH, temperature, and carbon dioxide availability in the sea water. In general, plankton living in warm waters of high pH shows the smallest C^{13} depletion, while plankton in cold waters of low pH is most strongly depleted in C^{13}.

An investigation of the C^{13}/C^{12} ratios of dissolved inorganic and organic carbon in sea water has been initiated. One of the aims is to detect changes with depth and to look for differences between water masses. Thus far the inorganic carbon has been analyzed in a few water profiles from the continental slope and the Sargasso Sea. A good correlation has been found between the C^{13}/C^{12} ratio and the dissolved oxygen concentration, especially in the region of the oxygen minimum layer. Near the surface the σC^{13} values of the inorganic carbon are near +1% on the PDB scale. They may be lower by more than 2% near the oxygen minimum. As the average value of the carbon in marine organisms lies around -15 to -20% one may conclude that a few percent of the carbon in the bicarbonate at the depth of the oxygen minimum are of organic origin, derived from the decomposition of biological detritus.

O^{18}/O^{16} and C^{13}/C^{12} Ratios in Red Sea Sediments

Oxygen and carbon isotope analyses of fossil Foraminifera and pteropods from the hot-brine deeps and surrounding sea floor of the Red Sea revealed considerable fluctuations in both O^{18}/O^{16} and C^{13}/C^{12} ratios with depth in all cores. Comparison of Foraminifera tests from inside and outside the deeps showed that isotopic exchange between the tests and the hot brine is taking place and suggests that hot brine has been present, at least intermittently, for the last 10,000 years. Fig. 1 shows a comparison of the data from two cores. Core 119K is from the *Discovery* Deep and 118K was collected six kilometers to the southeast. Reaction with the hot brine has compressed the amplitude of the fluctuations in 119K to less than half that in 118K and produced a mean shift of 1% in the direction of O^{18} depletion.

Pronounced changes in the isotope ratios at several depths can be correlated among cores from different locations. Such changes can be attributed to a combination of factors including changes in the temperature of the water in which the animals lived and formed their shells, periods of evaporation and increasing salinity of the Red Sea, and diagenetic changes in the sediment. O^{18}/O^{16} ratios in Foraminifera tests from a 9-meter core collected about 100 miles south of the deeps revealed at least three cycles of slowly increasing and then rather abruptly decreasing values. These cycles have been tentatively related to the glacial periods.

STOCHASTIC MODELING IN CHEMICAL OCEANOGRAPHY

Derek W. Spencer

We have considered the use of a first order Markov chain to describe and predict the distribution of elements and particles in sea water. In defining the model, different bodies of water may be established as states of the system. The amount of any element (or particle) that transfers from one state to another, in any unit time period, can be used to construct a transition probability, by considering the amount as a fraction of the total contained within the state in the same time period. A matrix of such transition probabilities can be considered as a first-order Markov chain. Given the assumptions that the process is stationary (i.e. the transition probabilities do not change with time) and that the particles or elements are inviolate, it is possible to utilize the theory of finite Markov chains to calculate some factors of interest to chemical oceanographers. With elements or particles in the ocean it is convenient to establish the bottom as an absorbing state (once a particle reaches this state it does not leave it). The transition matrix, P, may then be put into canonical form and partitioned as:

$$P = \begin{bmatrix} I & | & O \\ \hline R & | & Q \end{bmatrix}$$

where I is a unit matrix, O a zero matrix, R the matrix of transitions between transient and absorbing states, and Q the matrix of transitions between transient states. From the theory of absorbing Markov chains we can calculate N as $N = (I-Q)^{-1}$ where N is a matrix giving the mean number of times that a particle is in state i having started in state j. The row sums of N, given by $T = N1$ (1 is column vector of ones) are then the mean number of times that a particle, starting in state i, spends in transient states before it is absorbed. This, of course, is better known as the mean residence time.

To achieve some measure of reality it is necessary to consider an input of elements or particles into the system. If m is the vector of weights of particles in each state, at time zero, and f is a vector of the amount that is introduced into each state in the given unit time period then, after n time periods, the resulting vector g, the equilibrium distribution of particles, is

$$g = mQ^n + \sum_{o}^{n} fQ^k$$

as $n \to \infty$, $\quad Qn \to O \quad$ and $\Sigma\, Q^n \to (I-Q)^{-1}$

hence

$$g = fN$$

Thus the equilibrium distribution of particles may be calculated simply as the product of the vector of inputs, f, and the matrix of mean residence times within each state; it is independent of m. From g, R and the area of the bottom it is possible to calculate element or particle sedimentation rates.

Progress, to date, in the application of the model has been the completion of a computer program and the examination of selected areas of the ocean to test the model. It appears as if either the Mediterranean or the Baltic Sea will provide the best test.

TRACE ELEMENTS IN SEA WATER

Derek W. Spencer

The distribution of Fe, Cu, Zn, Co, Ni and Pb has been determined in waters from the Gulf of Maine and in sections across the Gulf Stream. All the measurements have been made in filtered water (0.45μ) using a solvent extraction procedure followed by atomic absorption spectrophotometry. Some of the more significant results are: (1) Trace metal contents show little direct relationship, either on a diurnal or annual basis to the level of plant nutrients. (2) Deep water in the Gulf of Maine appears to have relatively constant amounts of elements

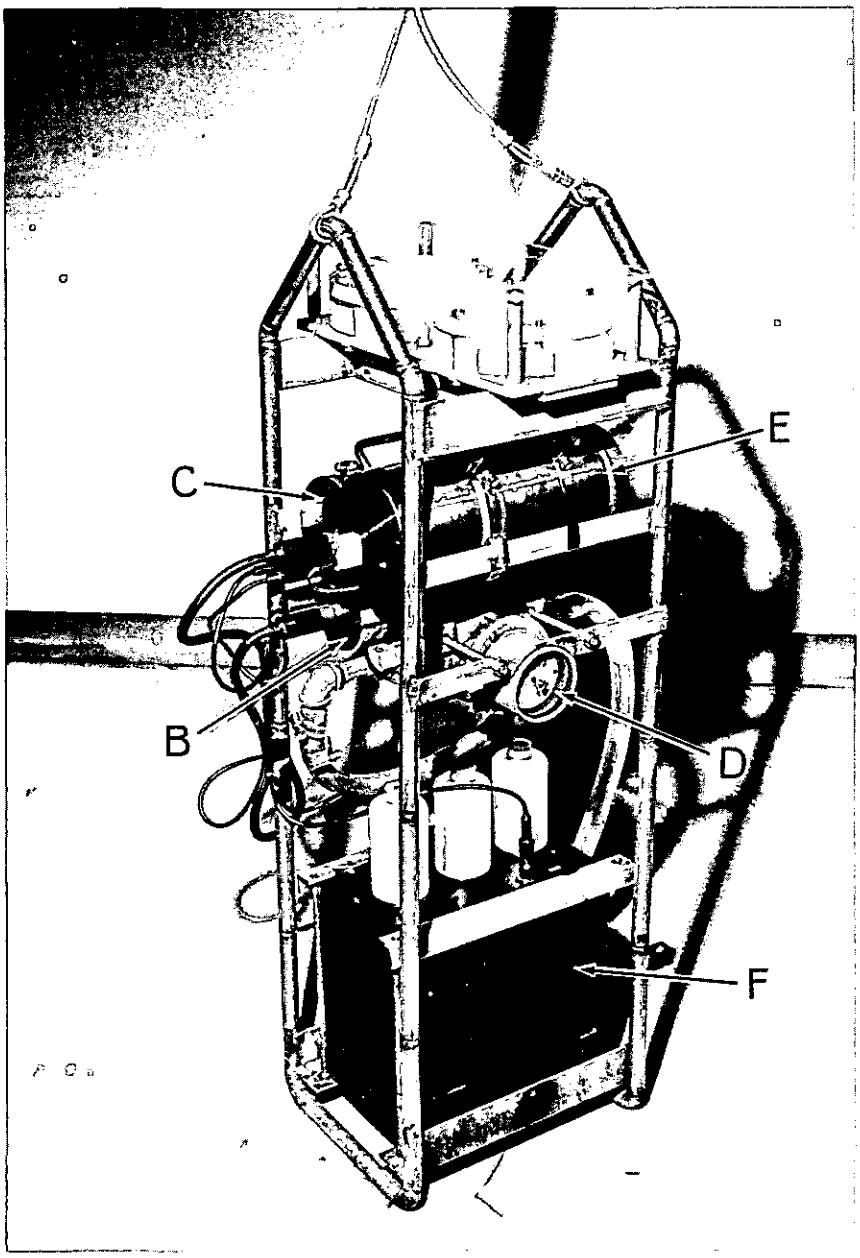


Fig. 1. (Sachs) Submersible filter pump. A. filter holders; B. pump; C. on-off timer and switch; D. flow meter; E. time-depth-flow rate recorder; F. pressure equalized storage battery.

throughout the year. (3) During the summer period, with a stable water column, surface waters close to shore have significantly higher concentrations of trace metals. (4) Atlantic Slope Water has higher levels of Cu, Zn and Ni than both the Gulf Stream and Sargasso Sea Water. These differences appear to be maintained throughout the year. No significant differences in the concentrations of Fe, Co and Mn could be detected. (5) Slope water trapped in the center of an isolated Gulf Stream eddy maintained its higher contents of Zn and Cu over a period of 7 months.

SEA WATER ANALYSES

P.G. Brewer

Fluoride in sea water

Work has commenced on a study of fluoride in sea water, principally by means of an Orion Research Inc. specific ion electrode. The membrane of the electrode consists of a laser-type single crystal of lanthanum fluoride doped with a small amount of a divalent cation such as Eu^{++}. This device will sense only the free, uncomplexed fluoride and hence can be used to measure the activity of fluoride ion in a solution of known concentration. Furthermore, by varying the concentrations of specific ions in a medium of constant ionic strength the effects of ion association may be investigated. Preliminary results show that ca. 50% of the fluoride in sea water is complexed with magnesium, presumably as an ion-pair, MgF^{+}, and we have been able to assign a total ion activity coefficient of ca. 0.39 for fluoride in sea water. It is hoped to incorporate the electrode into a continuously reading unit to measure fluoride concentrations *in situ* in the ocean.

Hydrographic Observations on the Red Sea Brines

The unusual chemical composition of the Red Sea brines precludes the use of standard oceanographic determinations of salinity, i.e. by means of conductive salinometer or chlorinity titration. Determinations of the true salinity of the brine samples have been made gravimetrically, and titrations of chlorinity have been carried out on samples from each of the brine pools. The data has been used in conjunction with the temperature and depth measurements made at sea to present an ordered picture of conditions in the deeps, and have shown possible evidence of heating, cooling, and further stratification of the brine in this complex area.

SUSPENDED PARTICULATE MATTER IN DEEP WATER

P. Sachs

A submersible pump capable of filtering large volumes of sea water *in situ* at any depth was constructed (Fig. 1). The apparatus will pass up to about 100 liters per hour through a pair of 142 mm dia., 0.45μ cellulose ester filters and furnish a split sample of the total particulate matter suspended in that volume. Rate of flow varies widely and is dependent on concentration and composition of the suspended phase.

One of the filters is ashed and processed for geochemical analysis. Particulate matter from the second filter is re-deposited on a silver filter and analyzed by X-ray diffraction for mineralogical composition.

Results of a study of suspended particulate matter with depth in the Gulf of Maine are condensed in Table I. This investigation was supplemental to related work in the Gulf of Maine and preliminary to work in deep water north of Puerto Rico planned for early 1968.

Table 1 Particulate matter concentration in Gulf of Maine waters.

	volume filtered (L)	partic. matter conc.(mg/l)	refractory at 500°C (%)
6 near-surface stations-mean	56	0.3	15*
9 near-bottom stations-mean	111	1.4	90

*estimate based on incomplete data

The data of Table 1 show that particulate matter suspended in water from 5 to 10 meters above the bottom is about five times as concentrated as that in near-surface water. Elaborate precautions were taken so as not to stir-up bottom sediments with the sampling gear. Near-surface concentrations are relatively uniform whereas near-bottom concentrations vary with bottom topography and location. Ash weights (after 12 hrs. at 500°C) are used to estimate the relative proportion of organic and non-organic components of the sample. Near-surface concentrations of silicates and other refractory particles are about 50 μg per liter whereas near-bottom concentrations are about 1250 μg per liter, twenty-five times as high.

More than sufficient material is available from the near-bottom samples to give good X-ray diffraction data (Fig. 2). Diffractograms from the near-surface samples are just good enough to indicate the presence of minerals, but not sufficient to allow quantitiative estimates. The mineralogy of the samples is closely related to that of bottom sediment samples obtained nearby and averages about 45% illite, 40% chlorite, 10% quartz and 5% feldspar.

A single sample from water 100 meters off the bottom in the Sargasso Sea indicates a particulate matter concentration of 0.4 mg per liter. The mineralogy of this sample again relates to that of the bottom sediment.

DIFFERENCE CHROMATOGRAPHY

R. Wilson

Although the relative proportions of the major ions of sea-salt have long been considered to be constant for all practical purposes, small variations in these concentration ratios do in fact occur. These minute variations are of interest because they may provide more information on the factors controlling major ion concentrations, and on the transporting water movements. Unfortunately, analytical procedures capable of detecting such small variations are both complicated and slow, and hence are unsuitable for large scale oceanographic application. In order to circumvent this difficulty the method of ion exchange difference chromatography has recently been developed at Woods Hole. The sample water is passed through a thermostated ion exchange column, preceded and followed by a standard known sea water of closely similar salinity. The differences between the sample and the standard emerge as a series of fronts or waves, which are detected by a highly sensitive membrane salinometer. As an illustration, the method has been shown to be capable of detecting an addition of 5×10^{-8} equivalents of K^+ to a 2 ml sample of sea water. There is little doubt that a study of the oceanic distribution of this and other major elements at such levels of sensitivity will add to our understanding of the processes which determine the chemical composition of the marine environment. The method is rapid, and we hope to adapt it to routine use in the near future.

NUCLEAR MAGNETIC RESONANCE STUDIES OF WATER-ELECTROLYTE AND WATER-NONELECTROLYTE INTERACTIONS IN SOLUTIONS RELATED TO SEA WATER

J.E. Gordon and J.C. Robertson

Proton magnetic resonance (pmr) spectrometry is a sensitive tool for the study of molecular structure, of intermolecular chemical interactions, and of medium effects in liquid samples containing ^1H nuclei. This is by virtue of the fact that chemical influences are sensed at the nucleus as variations in electronic shielding of the applied magnetic field. The spectroscopic line positions thus modified by microscopic electronic influences are termed chemical shifts.

Study of molecular structure.

Determination of structure of individual organic compounds isolated from marine specimens is greatly aided by knowledge of the pmr spectrum, although the latter is in general itself insufficient for structure elucidation. Recording pmr spectra of the small samples available requires use of a time-averaging computer. Experimentation with a prototype instrument (in cooperation with M. Blumer) in 1967 resulted in redesign of the unit by the vendor;

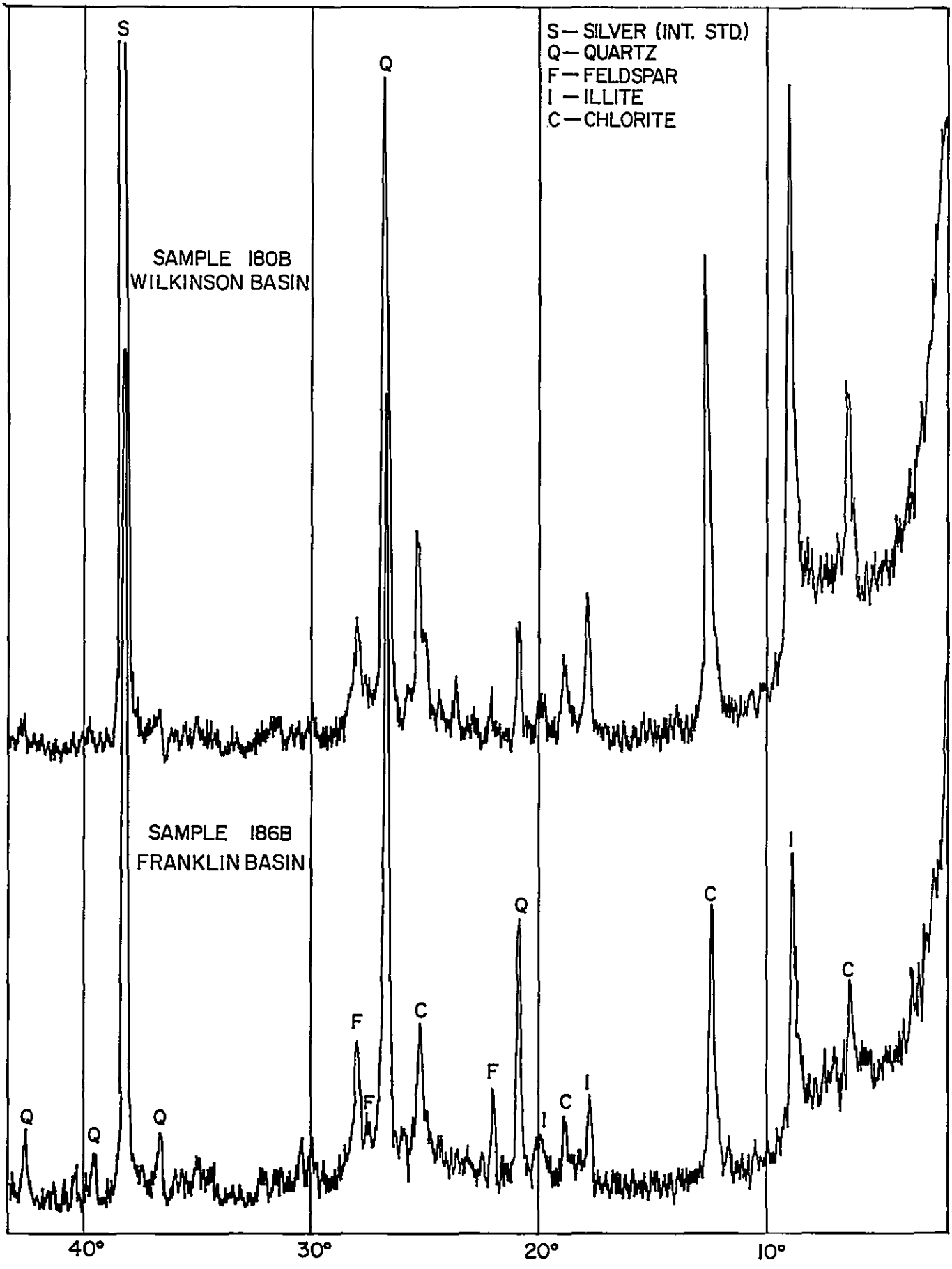


Fig. 2. (Sachs) X-ray diffractometer traces of material suspended in near-bottom water of the Gulf of Maine. Cu K α radiation; 40KUP; 40 Ma; 3.75°/min scan; 500 counts/sec full scale; TC 0.5 sec; oriented aggregates on silver filters.

installation of an improved version was scheduled for year's end.

Pure aqueous salt solutions.

Pmr chemical shifts of the water protons have been measured as a function of salt concentration for eleven pure salt systems. Measurements were made relative to four internal and an external standard. The non-linear dependence of chemical shift on salt concentration has been accounted for on the basis of overlap of the polarizing influences of neighbor ions in solution.

Salt effects on nonelectrolyte chemical shifts.

The measurements of the preceding paragraph also provide some information on nonelectrolyte--salt interactions. In the absence of salt effects on the chemical shifts of the nonelectrolytes (CH_3CN, CH_3SOCH_3, t-C_4H_9OH) used as internal references, identical water shifts should be observed vs each of the references. In fact the observed water shifts are always different for the three, but the three sets of data form a relatively constant pattern independent of salt identity. This is the result of salt-induced shifts of the references. A published explanation of the discrepancy between internally and externally referenced shifts in salt solutions was tested using these data and others involving a variety of reference structure variations. Neither that model nor any we have devised account for all of the observations, though many of them are rationalizable as preceding from specific chemical interactions.

Water Shifts in mixed electrolyte solutions.

Fifteen binary mixtures have been studied. Equations describing the water chemical shift for the mixtures in terms of parameters measured for solutions of the pure components follow directly from our model of the concentration dependence in the pure salt solutions. These are approximately obeyed; deviations can be analysed to give some information on discrete ion–water interactions. For example, evidence has been obtained for the importance of interactions of the following type in solutions containing the larger quaternary ammonium cations: $R_4N^+ \ldots\ldots (H_2O)_n \ldots\ldots R_4N^+$.

Solubilization and salting-in phenomena.

Measurements are being made on systems in which the solubility of an organic nonelectrolyte has been enhanced by the presence of an organic salt. Such solutions are of two kinds. In those containing long-chain organic salts there is good evidence that nonelectrolyte is solubilized in the interior of micelles whose structure is fairly well known. In solutions of short-chain salts, the salting-in mechanism is poorly understood; our work of last year indicated the importance of specific, short-range organic ion--nonelectrolyte interactions. Pmr spectra of such solutions are capable of yielding structural information complementing our thermodynamic results.

GEOLOGY and GEOPHYSICS

DEPARTMENT OF GEOLOGY AND GEOPHYSICS

Earl E. Hays, Department Chairman

The Joint Woods Hole Oceanographic Institution-U.S. Geological Survey Program for the Continental Margin

K.O. Emery

The staff remained at about the same level as during 1966: 13 scientists and 8 technicians at the Woods Hole Oceanographic Institution, plus 3 associated scientists at other institutions.

In accordance with plans given in the *Summary of Investigations in 1966*, no cruises were conducted for routine sampling of the type that was needed during the initial stages of the program, 1963 to 1966. Instead, cruises were conducted for special purposes by different members of the group for a total of 116 ship-days, as follows:

1. Helicopter-- sampling heavy minerals of Cape Cod beaches — 2 days
2. *A.E. Verrill* (MBL)--sampling deeply submerged oyster shells — 1 day
3. *Albatross IV* (BCF)--rock samples from Georges Bank — 5 days
4. *Eureka* (Shell Oil Co.)--interstitial waters of drill cores Gulf of Mexico — 10 days
5. *Caldrill I* (Humble Oil Co.)--interstitial waters of drill cores from off New England — 6 days
6. *Atlantis II*--interstitial waters of a piston core from the Gulf of Maine — 1 day
7. *Chain*--seismic profiling of Atlantic Continental Rise — 42 days
8. *Alvin* and *Lulu* (plus *Gosnold* or *Crawford*)--a total of 17 dives — 36 days
   a. Blake Plateau--manganese and phosphate deposits, 5 dives
   b. Continental shelf off Chesapeake Bay--submerged beach ridges, shellfish, evidence of early man (joint with Bureau of Commercial Fisheries), 2 dives
   c. Oceanographer Canyon--stratigraphy and topography, 2 dives
   d. Georges Bank--submerged peat deposit (joint with BCF), 1 dive
   e. Corsair Canyon--stratigraphy and topography, 1 dive
   f. Continental slope--topography and sediments, 4 dives
   g. Continental shelf off Newport, R.I.--microtopography (joint with Hudson Laboratories), 2 dives.
9. *Asterias*--used in conjunction with land-based refraction seismic studies on Martha's Vineyard and Nantucket Island. — 3 days

Cruises for 1968 are expected to be as diverse as those for 1967: Their objectives will include geophysical surveys, long coring, and observations from *Alvin*.

The year 1967 was an active one for publications of the group, because the joint program has now reached a stage of equilibrium in the distribution of effort between collection, processing, and reporting of data and observations. A total of 60 articles comprising nearly 1000 pages was published during the year by members of the group, mainly on the geology of the Atlantic continental margin, but also including reports on aspects of marine geology in the Caribbean Sea, the Red Sea, and the East China Sea. Forty more manuscripts are in press, and many others are in some stage of preparation. Members of the group also found time to give 45 talks at various scientific meetings, in addition to at least as many talks given at Woods Hole.

Seismic Studies on Martha's Vineyard and Nantucket Islands, Massachusetts

Robert N. Oldale

Refraction seismic studies were made on Martha's Vineyard and Nantucket in the fall of 1967 as the first step in a study of the marine nearshore areas of southeastern New England. Additional land-based seismic studies are planned on Cape Cod, Monomoy Island and north and west of Cape Cod to where crystalline basement rocks crop out. These data will be compared with seismic refraction data obtained offshore and will help in identifying layers recorded by continuous seismic profiling.

The seismic traverses on Martha's Vineyard and Nantucket were of the inline refraction type. Trasverses were made with a 12-channel portable refraction amplifier and oscillograph. Geophone spacing was 50 meters. The distance between the shot point and the first geophone was from 50 to 650 meters. Beaches were used to

obtain the longest possible tangents; the length of the seismic line was determined by the length of the tangent available. Three lines each 60 feet long with a 5-foot geophone spacing were made directly on Cretaceous sand and clay that crop out at the Gay Head cliffs, Martha's Vineyard.

The thickness of the layers was determined using the critical-distance method, recording low and intermediate velocities and true rock (basement) velocities. At most stations basement velocities were not recorded and the distance between the shot point and the last geophone was used as a minimum critical distance. At these stations the basement velocity was assumed to be 5577 m/sec, a value based on the average of the basement velocities recorded on Cape Cod. All stations were within a meter of sea level and thickness values are therefore considered to be altitude values.

Thirteen traverses were made on Martha's Vineyard and five on Nantucket. Most stations showed a single layer with velocities that ranged from 1470 to 1890 m/sec. This layer is composed at least in part of glacial drift of Pleistocene age. It probably includes unconsolidated sediments of Tertiary and Cretaceous similar to those that crop out at Gay Head. Computed thickness of the upper layer range from 98 to 322 meters on Martha's Vineyard and from 121 to 427 meters on Nantucket.

A second layer with compressional wave velocities of 1900 to 2230 m/sec was recorded at three stations on Martha's Vineyard and at two stations on Nantucket. This layer is probably partly compact glacial till similar to that identified in a borehole on Cape Cod, and partly unconsolidated Tertiary and Cretaceous sediments, similar to those on Block Island and in Cape Cod Bay. At Gay Head cliffs compressional wave velocities measured on the Cretaceous out-crops ranged from 723 to 1250 m/sec. These velocities are lower than velocities recorded for Cretaceous sediments elsewhere and probably are the result of the weathering in the upper part of the deposit.

Compressional wave velocities inferred to represent crystalline basement were recorded at three stations on Martha's Vineyard. No basement velocities were recorded on Nantucket. The recorded velocities ranged from 4540 to 8500 m/sec. True velocities ranged from 5380 to 5650 m/sec and are similar to velocities measured on the basement on Cape Cod and other parts of Massachusetts.

Depths to the basement surface, where basement velocities are recorded, ranged from 267 to 353 meters. At all other stations computed minimum depths to the basement surface ranged from 186 to 360 meters on Martha's Vineyard and from 227 to 427 meters on Nantucket. A basement velocity of 5730 m/sec and depth of 509 m, measured by Weston Geophysical Engineers Inc. at Nantucket in 1966, exceed our minimum estimates.

Bathymetry and Continuous Seismic Profiles of the Hot-Brine Region of the Red Sea

David A. Ross, Earl E. Hays and Frank C. Allstrom

A detailed bathymetric and geophysical study has been made of the three known deeps in the hot brine region of the central rift valley of the Red Sea. The largest, the *Atlantis II* Deep, is an elongate basin with an irregular and sometimes tilted bottom. The *Discovery* Deep is circular and flat-floored, and the *Chain* Deep is relatively narrow and V-shaped.

Continuous seismic profiling produced a distinct reflection from the hot brine-normal sea water contact in the *Atlantis II* and *Discovery* deeps. In contrast, reflections from the sediment-brine interface are commonly indistinct.

Continuous seismic profiling, acoustic returns from the lowering of a pinger to the sea bottom, and coring indicate that the deeps are covered with a thin veneer of heavy-metal rich sediments. Evidence from the pinger lowerings suggest that a major portion of the *Atlantis II* Deep contains more than 20 meters of heavy metal deposits. The sediment distribution in the brine area suggests a brine source in the *Atlantis II* Deep and periodic overflows into *Chain* and *Discovery* deeps at some time in the past.

A subsurface seismic reflector is common to records from the flanks of the deeps. If the age of this discontinuity is late Miocene or early Pliocene (as suggested by Knott *et al.*, 1966), a younger age for this part of the rift valley is indicated and the spreading rate of the rift valley since this time is about 0.3 cm/year. This value is considerably less than the spreading rate generally accepted for the Red Sea (2 cm/year) and suggests that either the discontinuity is not Pliocene-Miocene in age but perhaps Pleistocene, or rates of spreading in the Red Sea is smaller than expected.

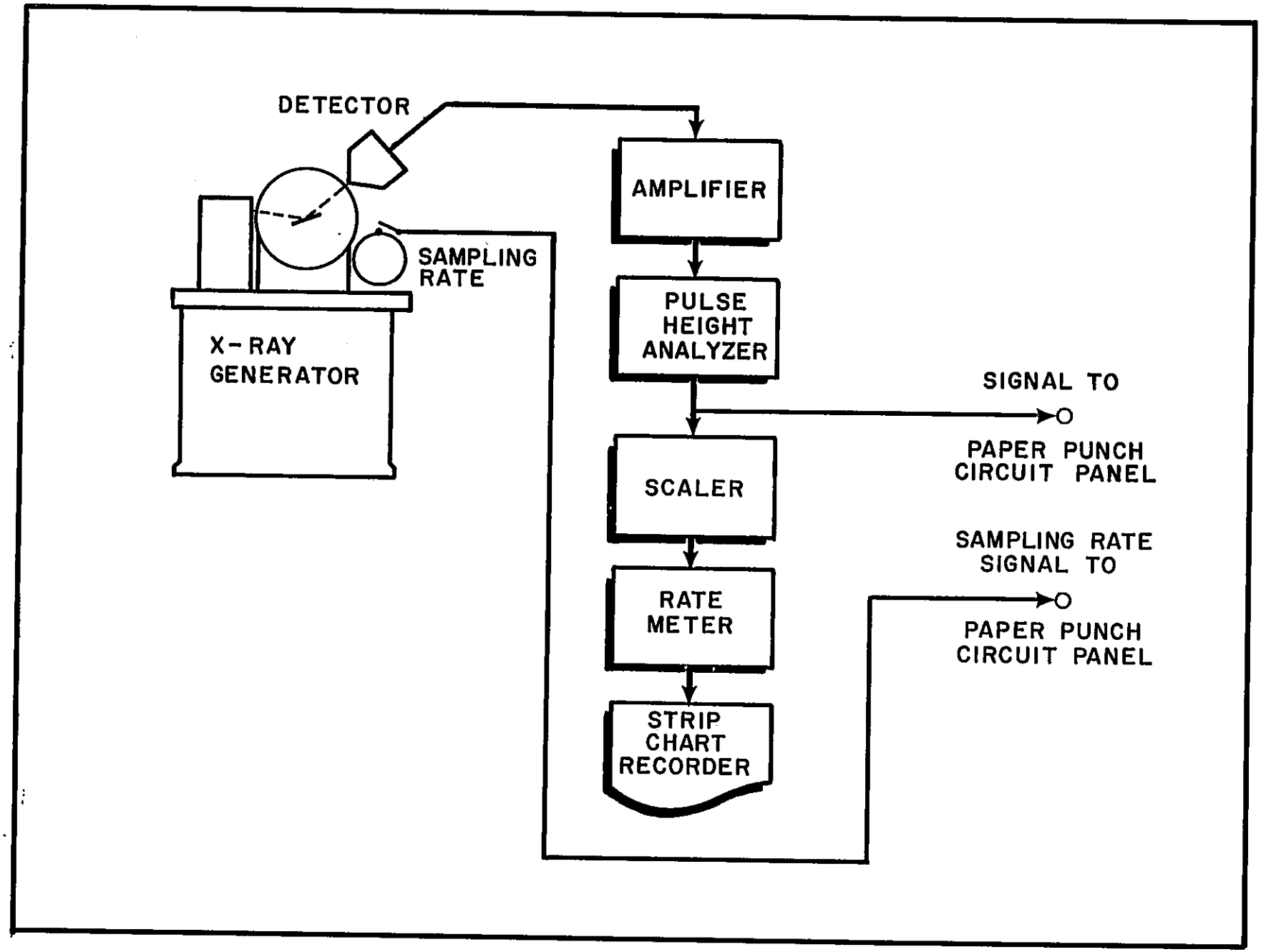


Fig. 1. (Hathaway) Diagram showing information flow in x-ray diffractometer and points at which data is transferred to punch tape unit.

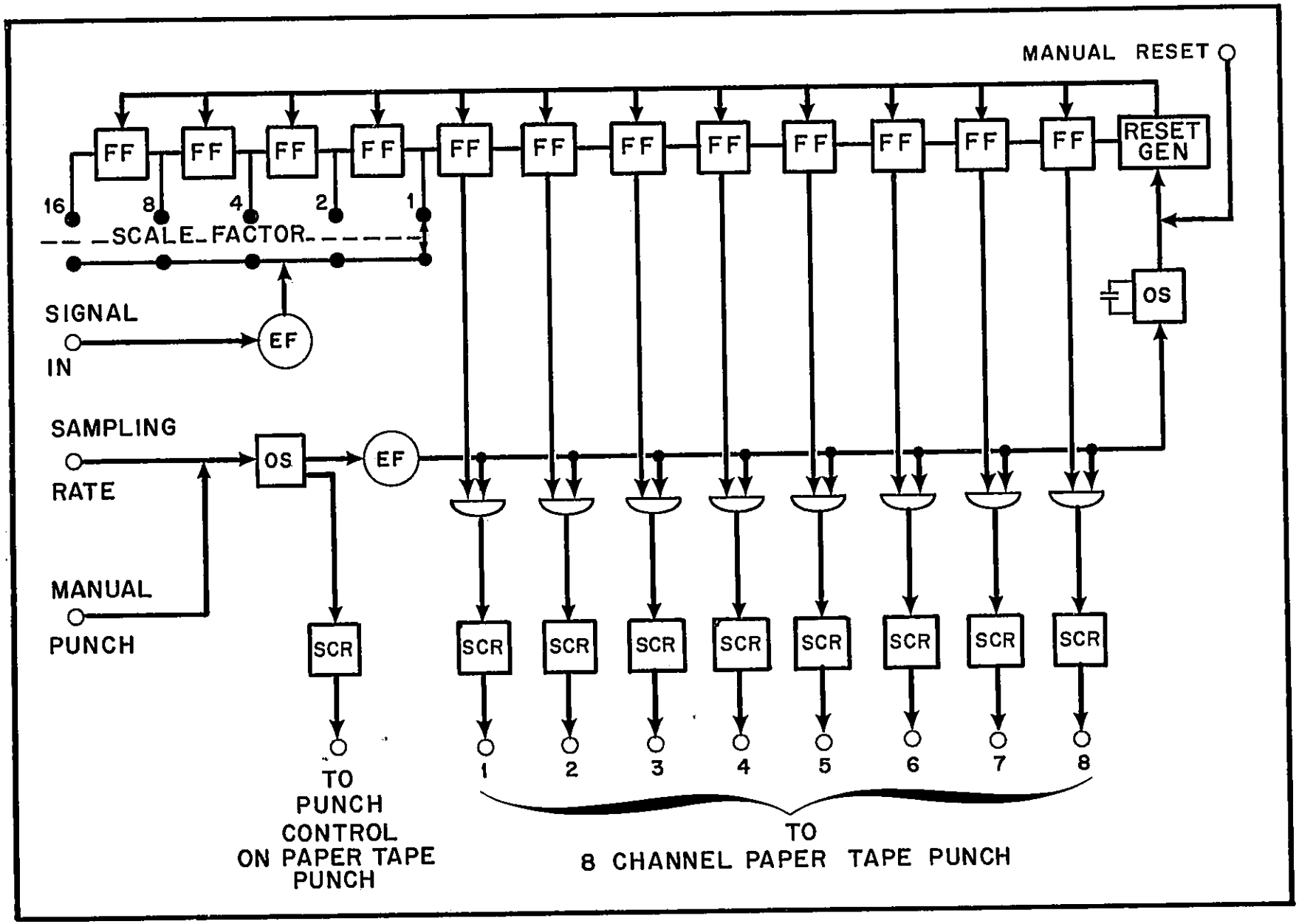


Fig. 2. (Hathaway) Schematic of punch tape data unit. FF = binary flip-flop multivibrator stages, EF = emitter follower, OS = one-shot multivibrator stages, SCR = silicon controlled rectifiers. Bowl-shaped symbols are AND gates. If both sides of a gate are closed, signal is passed to punch hole representing corresponding flip-flop stage.

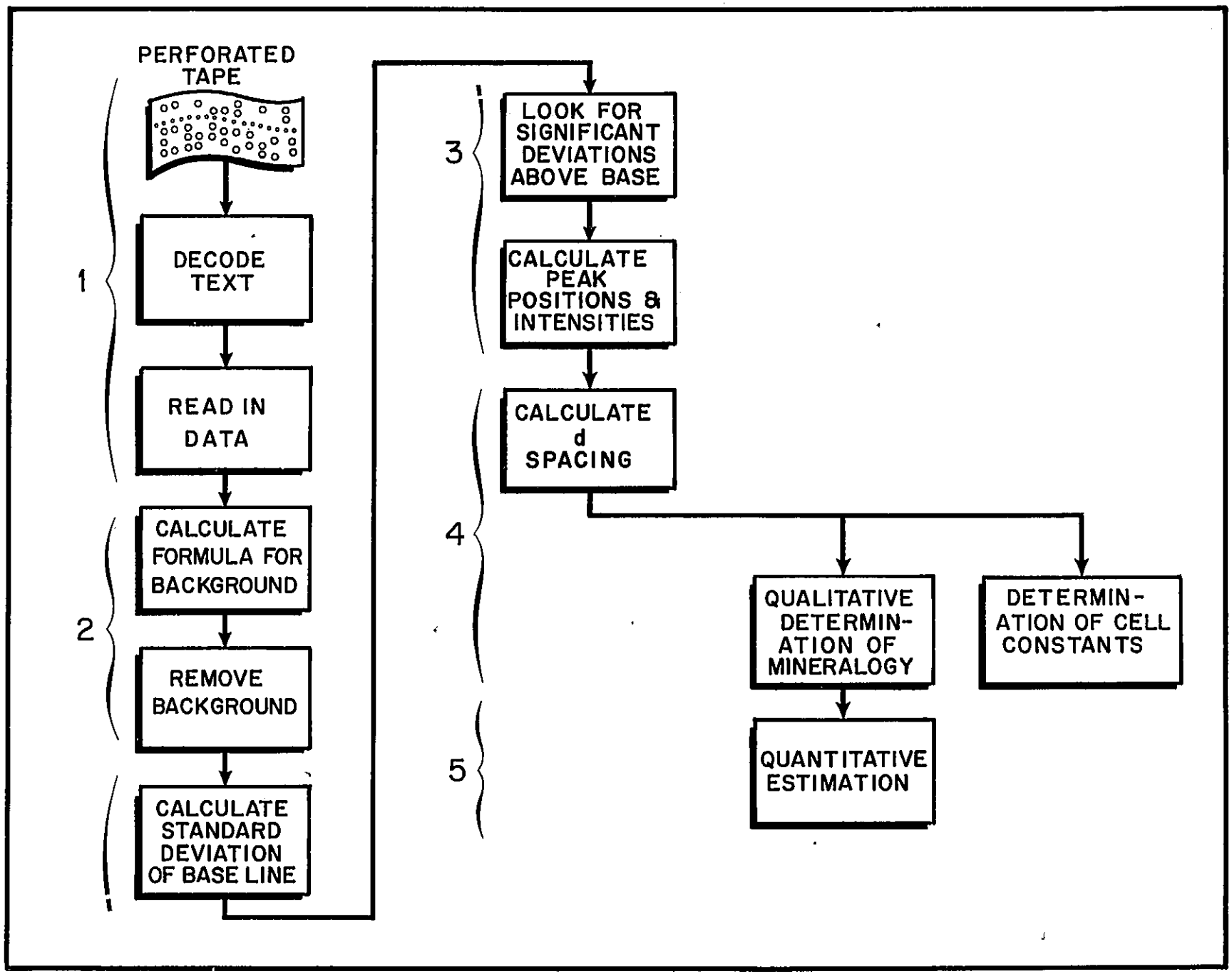


Fig. 3. (Hathaway) Flow chart of computer program for processing x-ray punch tapes. Brackets refer to chained stages of the program offset in flow chart in *Chain* 4 indicates stage to which programming is fully completed.

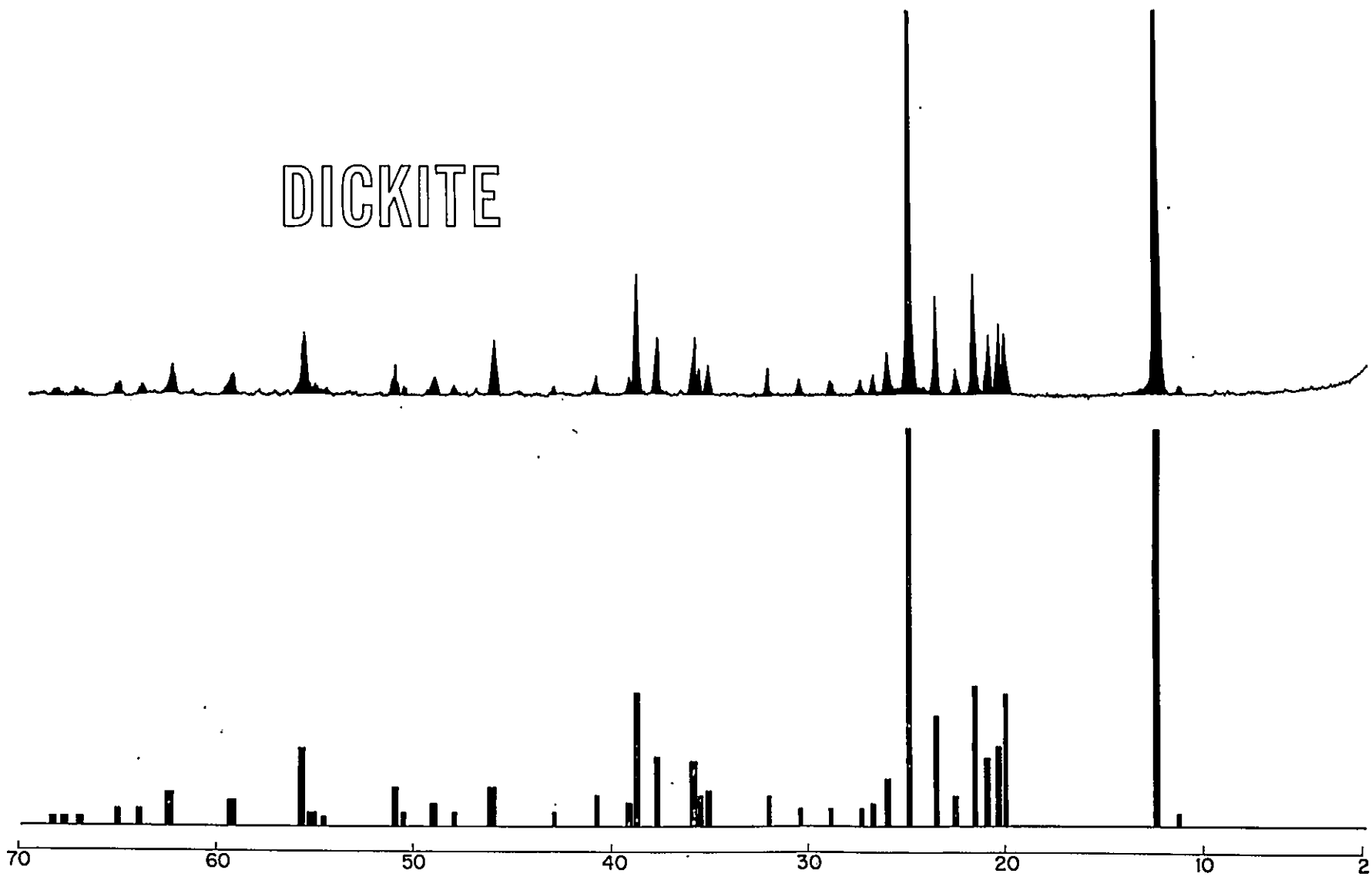


Fig. 4. (Hathaway) Upper trace shows strip chart recording of x-ray diffractometer pattern for dickite. Lower trace is plot of parameters determined by computer processing of perforated tape record.

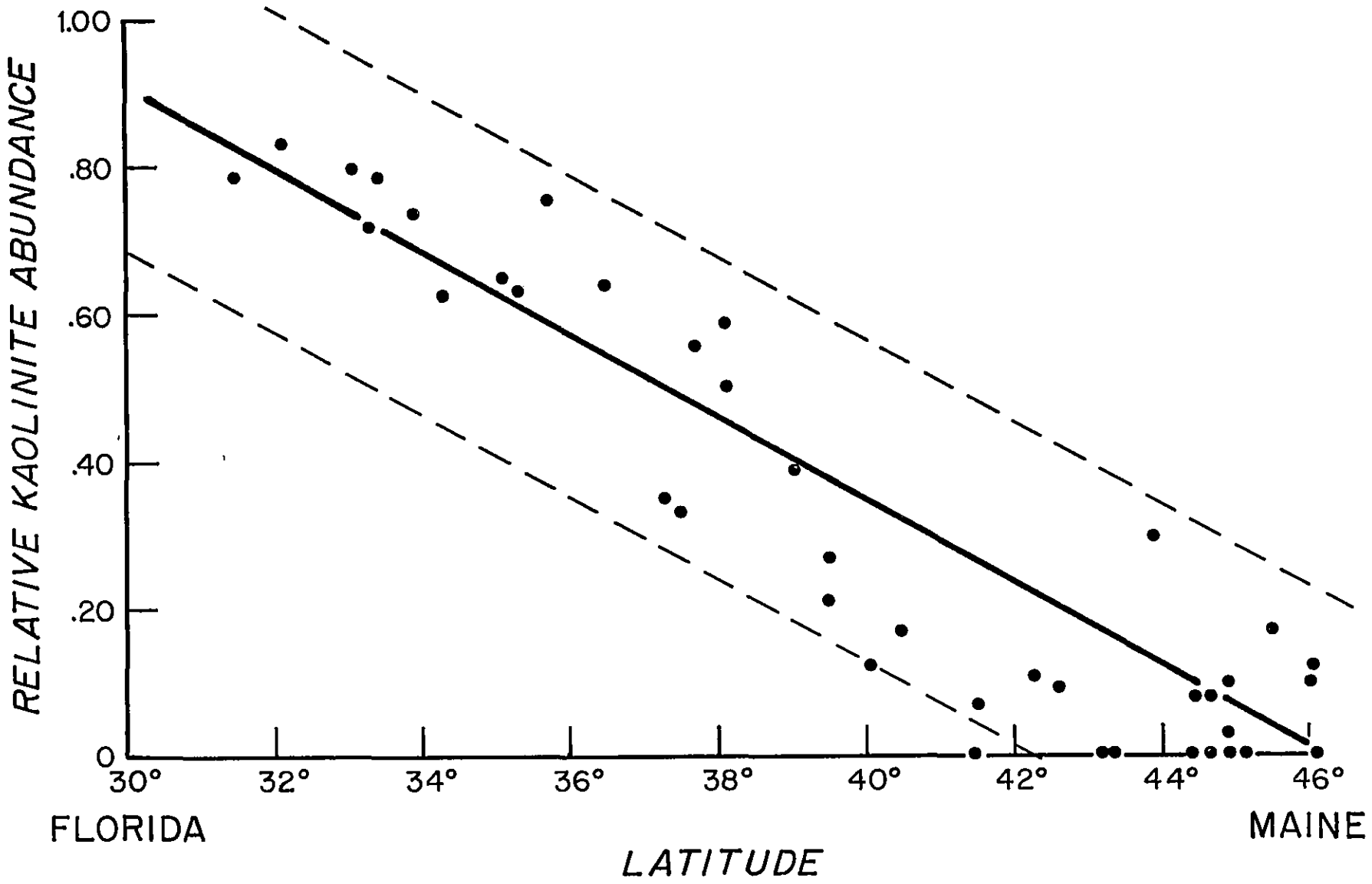


Fig. 5. (Hathaway) Kaolinite content of Atlantic coast river sediments versus latitude. Dotted lines show 95% confidence limits for the values about the regression shown.

Structure and Bathymetry

Elazar Uchupi

Structural studies of continental margins were continued during 1967. Reports describing the shallow structure of the margin between Cape Hatteras, North Carolina and Cape Kennedy, Florida, in the Gulf of Mexico (with Emery), off Dry Tortugas, Florida were submitted for publication. A detailed survey of the lower continental slope and upper rise off Block Island and Rhode Island suggest that slumping and gravitational sliding have played a significant role in molding the present surface morphology of the continental slope. During July, August and September, approximately 7200 km of magnetic, gravity, high-resolution echo sounding, and continuous seismic profiles were recorded on the continental rise between the Grand Banks of Newfoundland and Cape Hatteras, North Carolina. This survey is a cooperative venture between the geology and geophysics division within the Department. Data obtained during these two cruises will be used to determine the sedimentary framework and origin of the rise.

Bathymetric studies of continental margins were also continued during 1967. A report describing the bathymetry of the Gulf of Mexico was published. Two charts, at a scale of 1:1,000,000 of the sea floor off the Canadian Maritime Provinces were compiled from soundings of Canadian Hydrographic Service field sheets and navigational charts. The western sheet extends from the eastern edge of Georges Bank to the western edge of the Grand Banks of Newfoundland, and the eastern sheet from the western edge of the Grand Banks to Flemish Cap. The two sheets are in the same format as that used on the charts off the east coast of the United States and in the Gulf of Mexico and will be published in the near future by the Canadian Hydrographic Service.

Mineralogical Investigations, 1967

John C. Hathaway

Punch tape recording of x-ray data

A system for computer processing of x-ray diffraction data using perforated tape has been developed. Because the information from an x-ray detector is already digital, no analog to digital conversion is necessary. The output pulses from the pulse height analyzer of the diffractometer (Fig. 1) are accumulated in solid-state binary flip-flop stages (Fig. 2) and punched as straight binary information on 8-channel perforated tape. The punch interval is selected by an interchangeable cam that is directly coupled to the 2-theta indicator of the diffractometer. Identification and operating-variable information is entered by thumb-set wheels as a block at the beginning of each pattern. The resulting tape is the binary equivalent of the usual scan-type diffractometer pattern. The electronics for the punch-tape unit were designed and built by Edward Chute of the Woods Hole Oceanographic Institution.

A computer program (Fig. 3) transfers the punched information to magnetic tape, fits a polynomical curve to the background, and removes its effect. Peak positions, heights, widths, and integrated intensities are determined, recorded on magnetic tape, and printed. A plot of these parameters as determined by the program is compared with the original strip chart recording for the mineral dickite in Figure 4. The tape may be used as input for qualitative mineralogic analysis, quantitative estimation, and determination of crystallographic constants.

Clay mineralogy of east coast rivers

The clay minerals carried by rivers of the Atlantic coast of the United States show a systematic variation with geographic location. The relative abundance of kaolinite varies inversely as the latitude with a correlation coefficient of -0.91 (Fig. 5). Mica tends to vary inversely with kaolinite. Chlorite is important only north of latitude 40° N and virtually disappears south of latitude 38°N. Dioctohedral vermiculite occurs at all latitudes in roughly similar quantities. Montmorillonite occurs in a few samples, notably in rivers originating within the Coastal Plain rather than the Piedmont.

Mineralogy of samples dredged from canyons along east coast continental margin

The mineral assemblages in dredge samples from Norfolk Canyon north to Corsair Canyon along the Atlantic continental slope show a correlation with stratigraphy. Samples of Cretaceous and early Tertiary age tend to contain either montmorillonite or kaolinite with calcite, clinoptilolite, or opal. Samples of Later Tertiary and

TABLE 1

RELATION OF MINERAL ASSEMBLAGES AND AGES OF SAMPLES FROM EAST COAST CANYONS

	DOMINANT CLAY MINERAL ASSEMBLAGE			
Non-Clay Minerals (other than Quartz)	Montmorillonite or Kaolinite	Chlorite Mica and Moderate to High Kaolinite	Chlorite, Mica and Low Kaolinite	Glauconite
Calcite	Cretaceous-3* middle Paleocene-1 middle Eocene-1 late Eocene-1		Pleistocene-1	
Calcite and Clinoptilolite	Cretaceous-2 Paleocene-1 middle Eocene-1 early Eocene-2			
Opal	Cretaceous-1 early Eocene-1			
Dolomite			post middle Miocene-4	
None	Cretaceous-1 early Miocene-1 post middle Miocene-2		late Miocene-1	
Feldspar < 10%		Pleistocene-3 post Miocene-1	post Miocene-4 Undifferentiated Quaternary-6 Pleistocene-6	Pleistocene-1
Feldspar < 10%		Undifferentiated Quaternary-1	Undifferentiated Quaternary-2 late Pleistocene-Recent-2	

*number of samples

Quaternary age tend to contain chlorite and mica with various amounts of feldspar. Most samples with more than about 10 percent feldspar are of Pleistocene age. Table 1 summarizes these relations.

Data file, Atlantic continental margin

Supplement 1 (Hathaway, 1967) to Volume 1 of the Data File, Atlantic Continental Margin Program (Hathaway, 1966) was completed and issued during the year. It includes sample collection data for stations collected after the completion of Volume 1 and for land (including beach) samples. The supplement also contains tables listing cruises made as part of the program and the participating scientists.

Volume 2, Analytical Data, is in preparation.

References

Hathaway, John C., 1966. Data File, Continental Margin Program, Atlantic Coast of the United States, v. 1, Sample Collection Data. *Woods Hole Oceanographic Institution Ref.* 66-8, 184 pp.

Hathaway, John C., 1967. Data File, Continental Margin Program, Atlantic Coast of the United States, v. 1, Supplement 1, Sample Collection Data. *Woods Hole Oceanographic Institution Ref.* 67-21, 108 pp.

Sediment Texture and Bottom Currents on the Continental Shelf and Slope off Southeastern United States

Charles D. Hollister

Distribution patterns of textural parameters determined for more than 1000 samples on the continental shelf suggest that ocean bottom circulation has reworked the surficial sediments to such an extent that they are now nearly uniform in grain size (medium to coarse sand).

Beyond the continental shelf, near the western edge of the Blake Plateau, a narrow belt of comparatively fine (silt size) biogenous sediment at least 200 miles long occurs. This accumulation lies along the seaward margin of the Gulf Stream axis where the westerly flowing Antilles Current meets the northerly flowing Gulf Stream System.

Bottom currents associated with circulation of the Slope Water north of Cape Hatteras have not noticeably reworked the uppermost layers of hemipelagic silt and clay on the continental slope and upper continental rise.

Long Piston Coring from a Cable Ship

Charles D. Hollister

During the late spring of 1968 an experimental long piston corer will be tested at sea in almost 4000 meters on the continental rise off Nova Scotia. The following paragraphs outline some of the reasoning used during the last six months in arriving at a new approach to long piston coring in the deep sea.

The weight of a standard core 80 feet long is about one ton. In addition the weight of 10 to 15,000 feet of wire is about 2-3 tons and another 2-3 ton strain on the cable is occasionally needed to overcome the static friction of the core tube which is imbedded in the sea floor. The heaviest wire (about ½ in. diameter) traditionally used on even the largest research vessel usually has a working strength of about 7 to 10 tons and thus, due to weight limitations alone, significantly heavier apparatus capable of recovering much longer cores cannot be used in deep water with modern research ships.

It is clear that considerably stronger wire (and stronger winches) than that used on present vessels is required in order to handle the much heavier weights necessary for deep penetration and to withdraw sediment cores imbedded 100 feet or more in the sea floor.

Commercial cable ships have as standard equipment steel grapnel rope and cable drums capable of handling weights of over 30 tons. These comparatively large (generally over 300 feet long) vessels are also equipped with booms, cranes and winches necessary for launching and recovering long, heavy core apparatus.

Preliminary engineering calculations based on specifications of available well-casing pipe suggest that a 150 to 300 foot long core weighing 10 tons would be structurally sound, and with these considerations in mind, it is proposed that a heavy piston core be designed following the basic specifications of the standard piston core. This core could be handled using standard cable-ship deck equipment and would be designed to penetrate and recover up to 300 feet of unconsolidated deep sea sediment. With these long cores major scientific problems would be solved and many new ones brought to light.

Organic Constituents in Continental Shelf and Slope Sediments

Jobst Hülsemann

In 1967 some 3500 chemical analyses were made for calcium carbonate, organic carbon and nitrogen concentrations in surface sediment samples (Fig. 1). This brings to completion about 85% of the total samples collected by the WHOI-USGS program. The following is a brief summary of the results.

Calcium carbonate is less than 5% (by dry weight) on the shelf from Nova Scotia to just south of Cape Hatteras, N.C.; its concentration increases abruptly near the shelf break. South of Cape Hatteras, the shelf is roughly bisected by the 20% line of carbonate concentration. On the continental rise and on the Florida-Hatteras Slope carbonate occurs in excess of 30%. Noteworthy is the paucity of calcium carbonate in the Gulf of Maine. If water depth were the chief controlling factor, more variable and higher carbonate concentrations would be expected.

Organic matter, represented by the concentration of organic carbon, is scarce (less than 0.25% organic carbon by dry weight) in the shelf sediments, except for values in excess of 1.5% in the Gulf of Maine. Values are moderately high on the continental slope and upper continental rise. Lower parts of the continental rise, where sampled, contain little organic matter. Two areas on the continental slope (off the mouth of the Hudson and off the Chesapeake Bay) have very high organic carbon (greater than 1.5%), suggesting perhaps a causal relation to the inland waters, although the broad areas of the shelf in between are rather barren of organic matter. These extremely high concentrations may be a consequence of preservation of original material due to rapid deposition of sediment or even burial by slumps and subsequent erosion of surface material.

Both calcium carbonate and organic carbon content increase with depth of water. In part, the correlation between depth and organic matter probably is overshadowed by other factors, such as water temperature and sediment texture. Organic and nitrogen in the sediments correlate well with sediment texture; calcium carbonate does not. Organic matter is concentrated in the fine fractions, reaching greatest abundances where the sediments are finest such as in the basins of the Gulf of Maine and some parts of the shelf, such as south of Martha's Vineyard. Patchy occurrences of high and low concentrations of organic carbon is characteristic elsewhere on the continental slope, and may be regarded as a typical companion of sediment slumps.

Suspended Matter in Surface Waters of the Northern Gulf of Mexico

F.T. Manheim, J.C. Hathaway, and Elazar Uchupi

About 200 surface water samples, ranging from 150 ml to 1.8 liters were collected and filtered for suspended matter studies during a cruise in the Gulf of Mexico in the late fall of 1966. All samples were analyzed to determine total suspended matter and combustible organic matter, and were examined by petrographic microscope. A few dozen samples were collected on silver filters and analyzed for mineralogy by x-ray diffractometer.

Results, shown in Figure 1, reveal that concentrations of suspended matter greater than 1 mg/l. were restricted to within a few kilometers of the Florida coast, but extended more than 100 km off Louisiana and Texas. Concentrations within the central Gulf of Mexico were virtually always less than 0.125 mg/l. Suspensates from areas farther than 100 km from shore contained mainly combustible organic matter, only a part of which was attributable to living plankton. Microscopic examination of the suspended matter on filters showed diatoms, algae and Radiolaria dominant planktonts offshore, whereas large brackish and freshwater diatoms, spores and seed cases were noted near estuaries and river mouths. Pollutants such as soot, coal, and ash covered a wide band in the central-northern area as far as 400 km from land; processed cellulose fibers apparently due to toilet paper were also frequently noted. Previous studies in the Atlantic coastal area had shown these to be particularly common along the southern United States, and in the Straits of Florida. Their origin is still unknown.

The mineralogy of the suspensates shows three general zones corresponding to the pattern shown in Fig. 1. In Tampa Bay and the area off the western coast of Florida, however, suspended matter was dominantly low magnesium calcite or aragonite. These mineral assemblages roughly reflect mineralogy of bottom sediments in the given areas.

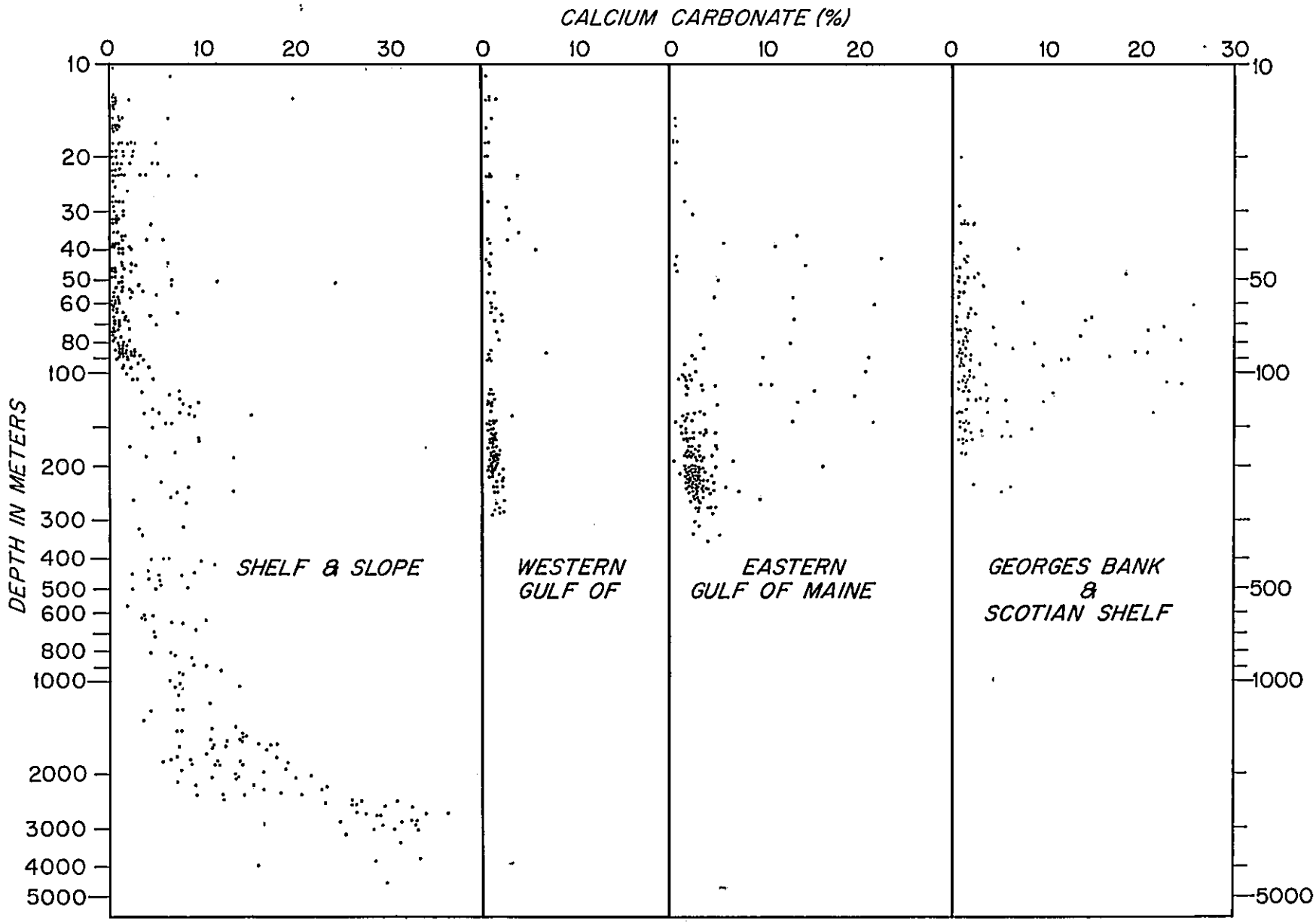


Fig. 1. (Hülsemann) A statistical summary of calcium carbonate of the sediments for the area between Nova Scotia and the Hudson Canyon.

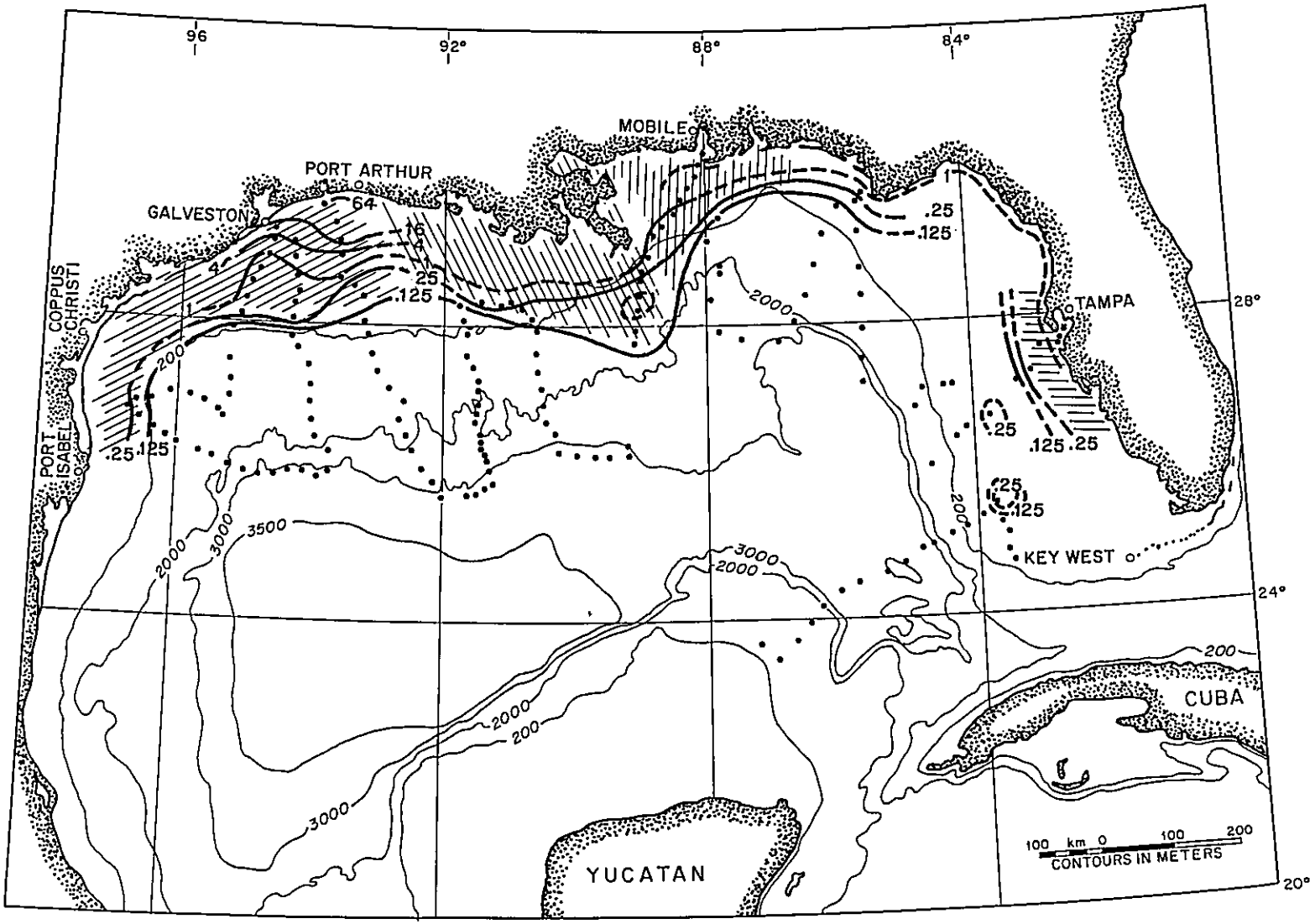


Fig. 1. (Manheim, Hathaway and Uchupi) Distribution of suspended matter in northern Gulf of Mexico.

Geochemistry of Manganese-Phosphorite Deposits on the Blake Plateau

F. T. Manheim and R. M. Pratt

Major deposits of phosphorite and manganese-iron oxides on the Blake Plateau have been evaluated. Estimated volumes and tonnages are shown in Table 1. These estimates include deposits at depths from 250 to 1000 m in the northern part of the Blake Plateau but do not include extensive phosphorite deposits exposed along portions of the entire Florida-Hatteras continental shelf and slope.

Based on analyses of over 100 samples by a variety of methods, as well as lithologic, petrologic and mineralogical data, average chemical compositions of the several types of deposits have been estimated (Table 2). The Blake manganese-iron nodules differ from average deep sea nodules in having markedly lower silicate rock constituents, especially Si, Al, and Ti, and in having higher calcium carbonate and phosphate concentrations. Among the trace elements, the nodules contain less copper than most deep sea nodules having comparable cobalt and nickel concentrations. The separation between silver and gold in the Blake manganese nodules is among the greatest yet observed in natural earth materials.

Although both the phosphorite and manganese concentrations compare unfavorably in ore grade with available land deposits or with oceanic nodules from certain areas, the great quantity of the Blake deposits, their relatively shallow depths and proximity to the continental United States make them a possible future economic resource.

TABLE 1. DISTRIBUTION OF MINERAL DEPOSITS ON THE NORTHERN BLAKE PLATEAU

Type of Deposit	Estimated Thickness	Area (km^2)	Vol. (m^3)	Tonnage
Phosphate nodules	10	7.4×10^3	7×10^8	2×10^9
Mn-phosphate pavement and nodules	5	9.4×10^3	4.6×10^8	1.2×10^9
Mn-Fe nodules	2	5.1×10^3	1×10^8	0.25×10^9

TABLE 2. ESTIMATED AVERAGE COMPOSITION OF BLAKE DEPOSITS AND COMPARATIVE MATERIALS

	Phosphorite	Pavement and Slabs	Round Nodules	Avg. Deep Sea Nodules	Mn ore (48%)
SiO_2	3.7	2.1	2.7	16.2	3.4
Al_2O_3	1.1	1.5	2.4	4.6	0.80
Fe_2O_3	4.1	9.2	15.8	16.7	2.7
Mn_3O_4	0.45	17.7	20.5	26.2	66.5
TiO_2	0.15	.28	0.44	0.94	0.70
CaO	50.0	31.1	16.8	2.2	1.1
MgO	1.2	2.6	3.4	2.3	0.2
SrO	0.18	0.26	0.20	0.07	0.1
BaO	0.006	0.22	0.22	0.17	2.6
K_2O	0.30	0.33	0.29	0.82	3.2
Na_2O	0.67	0.72	1.1	2.8	0.5
CO_2	11.4	7.2	8.1	0.61	0.3
P_2O_5	22.2	9.9	.80	0.44	0.2
F	2.3	1.0	<.10	-----	----
lg. Loss	14.9	23.0	28.2	25.0	17.5
U	0.01	≤0.001	0.0009	0.0007	----
Ni	0.004	.27	0.43	.58	.005
Co	<0.01	.1	0.3	.28	.01
Mo	<0.005	.03	0.035	.04	.02
Cu	0.007	.09	.13	.40	.05
Zn	0.015	.040	.058	-----	.05
Pb	0.03	.071	.11	.10	.3
Ag (ppm)	5	(4)	3	6	----
Au (ppb)	7.2	(2)	.2	-----	-----

Sediments in Estuaries of the Atlantic Coastal Plain

Robert H. Meade

Despite the suggestion by laboratory experiments that suspended matter in rivers is flocculated and deposited where it reaches salt water, the concentrations of suspended matter in estuaries associated with some moderately large rivers of the Atlantic seaboard show no accelerated decrease that can be attributed to salt flocculation. Velocities of the estuarine waters are apparently sufficient to obscure the expected effects of salinity and keep the material in suspension. The general decrease in suspended matter associated with increasing salinity in the seaward direction can be attributed to the simple dilution of river suspensions by sea water.

Superimposed on the general seaward decrease in suspended concentration is a maximum concentration near the upstream limit of sea salt. Suspended concentrations decrease both upstream and downstream of the maximum. This maximum has been found at one time or another in all the estuaries that have been sufficiently studied. It seems to reflect the accumulation of suspended matter near the salt limit by net landward flow along the estuary bottom.

Sediment is moved landward within the deeper parts of estuaries of the Atlantic Coastal Plain. Studies of the variations in the suspended-matter concentration and water velocity with depth and time through tidal cycles in estuaries show that sediment is moved progressively landward along the bottom. Comparisons of the loci of sediment deposition and the patterns of water circulation show that sediments accumulate near the upstream limit of landward bottom flow. Remains of estuarine organisms are found landward of their living range.

Offshore and longshore sediments may be moved into the mouths of estuaries. Over the long term, bottom waters of the continental shelf move into the estuary mouths. Beach sands move progressively toward and into the estuaries. Distinctive mineral components in the lower reaches of some estuaries seem to be derived from offshore.

The evidence for landward transport, however, is clouded by two main weaknesses. Most of the supporting data represent average conditions whereas most sediment is moved during infrequent floods and storms. Secondly, the influence of man is so pervasive in many estuaries that it obscures the natural conditions and processes.

Sedimentary Petrology - Atlantic Continental Margin

John D. Milliman

During 1967 a petrologic study of sand-sized (2000-62 microns) sediments on the continental margin, between New Jersey and South Carolina, was begun. A total of 371 surface sediment samples, collected by the USGS-WHOI group, were studied. In addition, over 1900 shelf and upper slope surface samples, collected between Cape Hatteras and Cape Canaveral were obtained from Dr. O. H. Pilkey, Department of Geology, Duke University.

Two basic textural sediment types are present on the continental shelf. Coarse to medium-fine sands, subangular to round, often with high percentages of iron staining, cover the outer and middle portions of the shelf. These sediments are thought to be relict, deposited during or before the last transgression of the sea. The other sediment type is represented by very fine sands (125 to 62 microns), angular to subangular, rarely iron stained. These sediments, located on the inner shelf near Delaware Bay, Chesapeake Bay and Pamlico Sound, may represent Recent sedimentation.

Continental shelf sediments are composed mainly of quartz, with supporting amounts of feldspar and rock fragments and lesser percentages of heavy minerals. Sediments between Cape Lookout and Cape Fear contain varying amounts of phosphorite, usually in pelletal form; highest concentrations occur on Frying Pan Shoals, Cape Lookout Shoals and along the outer shelf break. The phosphorite is thought to be derived from nearby phosphatic Miocene (Yorktown?) outcrops.

The shelf sediments north of Cape Hatteras seldom contain more than a few percent $CaCO_3$. Molluscs with lesser amounts of Foraminifera and echinoderms contribute most of the carbonate. In contrast, sediments south of Cape Hatteras, which generally contain more than 10 percent (and locally as much as 90 percent) carbonate, are characterized by definite and more complex carbonate assemblages. On the inner shelf, molluscs, with supporting amounts of barnacles and echinoderms, are the major carbonate contributors. Further offshore oolite and pellets are common. On the outer shelf shoal-water coralline algae and barnacle plates mix with deeper water Foraminifera. Limestone and phosphatic limestone fragments are locally abundant on Frying Pan Shoals and the inner portion of

Onslow Bay, suggesting nearby rock outcrops. Details on the carbonate distribution are presented in a manuscript prepared by J. D. Milliman, O. H. Pilkey, and B. Blackwelder.

The amount of sand in continental slope and rise sediments rarely exceeds 10 percent. This sand is very fine, angular to subangular, and rarely iron stained. Pelagic Foraminifera generally comprise over half the sand fraction with supporting amounts of quartz and feldspar. South of Cape Hatteras, on the Hatteras-Florida Slope and the inner Blake Plateau, glauconite-filled Foraminifera are the dominant sand components. The outer Blake Plateau is characterized by a gravel-sand deposit, comprised of Foraminifera, pteropod and coral carbonate debris, phosphatic rocks and manganese nodules.

Recent Sedimentation in the Gulf of Maine

David A. Ross

Sediments collected in the Gulf of Maine adjacent to the Penobscot, Kennebec and Merrimack Rivers have heavy-mineral assemblages similar to those of the river sediments. The heavy-mineral assemblages both of the rivers and the adjacent areas conforms with those expected from the rocks exposed in the drainage area of the rivers. These sediments are interpreted as Recent in origin, while the more offshore sediments are probably Pleistocene or glacial in origin.

Gravelly Sediment on the Continental Margin off the Northeastern United States

John Schlee and Richard M. Pratt

Gravel is distributed widely on the eastern United States continental margin but most of it is in the Gulf of Maine, Scotian Shelf, and northern part of the Georges Bank. Its areas of abundance are related to Pleistocene glaciation--a glaciation which has shaped the topography and dispersed much of the gravel.

Most coarse detritus in the Gulf of Maine is exposed on ledges and shallow banks, as well as the hummocky topography between basins. It is a very poorly sorted multimodal mixture of gravel, sand, silt, and clay. Gravel clasts are angular to subangular and composition is varied--apparently reflecting local bedrock composition.

On Georges Bank and Nantucket Shoals, the gravel is better sorted, more quartzose, and better rounded. It is associated with sand waves and tidal ridges in both areas. Gravel is very coarse and abundant in the exit channels which lead seaward from the Gulf of Maine across the continental shelf; the abundance of gravel gives further evidence these channels were outlets for tongues of glacial ice during the Pleistocene.

Scattered occurrences of gravel are on the continental slope as far south as Hudson Canyon. On the non-glaciated shelf south of New England, gravel has a patchy distribution in quartzose and has a bimodal size distribution; largest concentrations are associated with the drowned Hudson channel east of New Jersey.

Interpretation of gravel distribution allows us to (1) fix approximate limits of glaciation on the continental shelf, (2) interpret the bedrock geology of the Gulf of Maine and Scotian Shelf, and (3) list the agents which dispersed the gravel. Extending eastward from the glacial moraines on Nantucket and Martha's Vineyard, gravel is concentrated north of a line that runs in a loop-like fashion across Great South Channel and the northern part of Georges Bank. It continues across the seaward terminus of Northeast Channel and along the seaward edge of the Scotian Shelf. Assuming this concentration of coarse detritus marked the most seaward extension of ice, it means that most of Georges Bank was subaerially exposed during low stands of sea level, and that meltwater streams probably drained south to the shelf edge, there to dump detritus into the many submarine canyons which incise the southern part of Georges Bank. The boundary offers further evidence that the ice extended at least to the edge of the Scotian Shelf, there to form a sea-ice boundary with the ocean.

Local abundances of distinctive rock types gives some inference on the bedrock geology of the Gulf of Maine and Scotian Shelf. Sedimentary rock of probable Triassic age contributed detritus to much of the northeastern Gulf and Bay of Fundy, and probably underlies these areas. Sedimentary rocks of Cretaceous and younger age contributed rock fragments in the southern Gulf and some of the "vein" quartz pebbles abundant on Georges Bank and Nantucket Shoals. Granite and felsite clasts are abundant off the central Maine coast, southeastern New England,

and the Scotian Shelf. Spotted schist and gneiss are concentrated southwest of Nova Scotia, and along with granite and felsite these rocks are thought to underlie much of the inner Scotian Shelf. East of Massachusetts and New Hampshire basic igneous rocks contribute substantial detritus. Remaining portions of the Gulf (west of Wilkinson Basin; Northeast Channel; Crowell Basin) are a mixture of all types. Resistant rock types ("vein" quartz, quartzite, and chert) are mainly south of the Gulf and probably represent a mixed provenance. Some was likely brought in from crystalline bedrock beneath the Gulf by glaciers. Some also may have been derived from quartzose conglomerates in strata of Cretaceous age, thought to underlie Georges Bank and the southern Gulf of Maine.

Glaciers moving southward from New England and Canada sculptured the northern continental margin and contributed the poorly sorted till-like mixtures of gravel, sand, silt, and clay. Further, they dumped debris along northern Georges Bank as moraines and outwash plains. Hence the moderate sorting, better roundness and increase in resistant rock types we find in gravels on Georges Bank, Nantucket Shoals, and portions of the Scotian Shelf, reflect some current transport by both meltwater streams and marine bottom currents. Ice rafting has contributed coarse debris to the continental slope and rise; we find this reflected in the wide variation in rock types and roundness (pointing to a multiplicity of sources) and in the "tacked on" nature of the gravel fraction to the main part of the grain size distribution.

Foraminifera

Thomas G. Gibson

The study of the foraminiferal faunas from rocks dredged off the northeastern coast of the U.S., primarily in submarine canyons from Norfolk to Georges Bank, was completed. Ages range from late Cretaceous to Recent. The number of samples for each age is as follows: late Cretaceous-10, late Paleocene-1, early Eocene-4, middle Eocene-2, late Eocene-1, Oligocene-2, early Miocene-1, late Miocene-1, and Pliocene or Pleistocene to Recent-52.

Rock and sediment samples collected on the eastern side of the Tongue of the Ocean, Bahamas by John Schlee in the deep-diving submersible *Alvin* were also studied. The rock sample in the lower part of the Tongue of the Ocean is late Miocene-early Pliocene in age, with younger ages of Pleistocene and Pleistocene to Recent for higher rocks. These ages showed the Tongue of the Ocean to be a feature at least as old as late Miocene-early Pliocene; however, the rocks in the sides of the Tongue are much younger than those at equivalent depths under the islands surrounding it, indicating some structural deformation. The six rock and sediment samples all contain a considerable amount of shallow water detritus, apparently swept off the surrounding shallow banks, indicating that similar sedimentational processes have been going on in the area for 5-10 million years.

Most of the work on the dead Foraminifera from sediment samples in the area from New Jersey to Nova Scotia has been completed. The major effort at present is with the living specimens from the preserved samples. Two primary aspects are being studied in the living specimens.

(1) A careful comparison is being made of the living and dead species counts to ascertain areas of faunal mixing either due to downslope movement of specimens or residual specimens from the raising of sea level since Pleistocene time. The only areas of extensive mixing of shallow water species in presently deeper waters is south of the Great South Channel and in the northeastern part of Georges Bank and southern part of Browns Bank. These are both areas of extensive current activity, and it appears that the mixing is due to this agent. This means that although oyster shells, mastodon teeth, and peat deposits indicative of lower sea level have been left in certain areas, most of the Foraminifera indigenous to lower sea level have either been mechanically removed or destroyed.

(2) The study of the living specimens in proportion to dead ones has been shown to be the best foraminiferal method for determining rate of sedimentation. The higher the proportion of live, the faster the rate of sedimentation. This criterion indicates that the slowest rates are in the area of the outer shelf, and the highest rates are generally near the river mouths entering the Gulf of Maine and in nearshore areas around islands such as Nantucket and Martha's Vineyard.

Ostracodes

Joseph E. Hazel

Studies of the Recent benthonic ostracodes of the shelf and slope from Nova Scotia to New Jersey were continued this year. A taxonomic study of two of the most important families, the Hemicytheridae and Trachyleberididae, was published in the spring. A paper entitled "Ostracode Zoogeography in the southern Nova Scotian and northern Virginian Faunal Provinces", using the R/V *Gosnold* and Bureau of Commercial Fisheries ships' samples from the Nova Scotia to New Jersey region, has been completed and submitted for publication. A zoogeographic study of the Pleistocene ostracodes found in dredge samples from Atlantic Coast submarine canyons has also been completed and submitted for publication. In addition to the Pleistocene, Upper Cretaceous and Tertiary ostracode assemblages have also been identified from the submarine canyon dredgings. A manuscript concerning these samples (in conjunction with T. G. Gibson and J. F. Mello of the U.S. Geological Survey) is in preparation.

Summarizing the zoogeographic studies, there is a distinctive difference between the ostracode assemblages in the northern Virginian and southern Nova Scotian (= Acadian) Faunal Provinces. Many sublittoral cryophilic species are not present south of Cape Cod or the Northeast Channel. Several thermophilic species are not found north of Cape Cod or the Georges Bank. The assemblages of the southern part of the cold-temperate Nova Scotian Province are a mixture of amphiatlantic cryophilic species and endemic, mainly thermophilic, species; the amphiatlantic forms make up about fifty per cent of the total. Less than twenty-five per cent of the species known from the mild-temperate Virginian Province have been reported from European waters. More thermophilic endemic species pass Cape Cod from the south than do cryophilic amphiatlantic species from the north. This is consistent with the fact that there is a stronger compression of summer than winter isotherms in the Cape Cod region, and most of the amphiatlantic species are regulated equatorward by summer high temperatures.

The Pleistocene ostracode assemblages found in the submarine canyon dredgings are interpreted to represent a glacial interval or intervals. Species which are now restricted to north of Cape Cod and the Georges Bank occur in the various submarine canyons as far south as Baltimore Canyon. The assemblages recovered from Norfolk and Washington Canyons resemble those presently found in the northern part of the Virginian Province. These data suggest that at some time during the Pleistocene the boundary between cold- and mild-temperate sublittoral faunas lay approximately between Baltimore and Washington Canyons. Compared to the Recent, this is a faunal shift of about 500 miles.

Benthic Biology

Roland L. Wigley*

Rather clear patterns of the geographic and bathymetric distributions of benthic invertebrates that inhabit the continental shelf and slope between Hudson Canyon and Nova Scotia have emerged from analyses made during the past year. A major objective of our study has been to determine the density distribution of the many species and higher taxonomic groups of macrobenthic invertebrates within this area.

One aspect of general interest that may serve to illustrate these results is the quantitative geographic distribution of all macrobenthic species combined. Our measures of quantity or density include (1) the number of individual specimens and (2) the weight of animals. Both of these measures reveal a similar geographic pattern of density. The macrobenthos is most plentiful (averaging 1,000 to 5,000 specimens and 100 to 500 grams per square meter of bottom) on the continental shelf in a broad band around the periphery of the Gulf of Maine and extending southward along the coastal area to New Jersey, and offshore in southern New England to the Hudson Canyon region. A particularly large area of high abundance occurs in a band 30 to 60 miles wide in the region south of Martha's Vineyard and extending eastward about 150 miles to the eastern part of Georges Bank. Low densities (less than 100 specimens and less than 50 grams per square meter of bottom) of benthic animals generally occur in the deeper portions of the Gulf of Maine, the shelf area southeast of Nova Scotia, and in the offshore deepwater beyond the edge of the continental shelf.

The bathymetric analysis of these data also reveal that benthic invertebrates in this region are most abundant in shallow water, and that they diminish in abundance with increasing water depth. At depths less than 25 meters the average number of specimens is 2,500 per square meter of bottom. Only slightly lower densities (2,200 specimens) occur at depths between 25 and 100 meters. At depths greater than 100 meters the drop in density is much more

*Bureau of Commercial Fisheries Biological Laboratory, Woods Hole, Mass.

pronounced; from 100 meters to 1,000 meters the number of specimens decrease from 900 to 300 per square meter. And between 1,000 and 2,000 meters the average density is 120 animals. The lowest abundance of invertebrates (75 per square meter) occur on the continental rise, which is the deepest region (2,000 to 4,000 meters) that we have sampled.

Photographs of the sea bottom are a valuable source of information about benthic animals and bottom topography. A series of photographs taken by the R/V *Albatross IV* on Georges Bank last spring showed a variety of bottom-dwelling fishes (winter flounder, yellowtail flounder, oceanpout, skates, longhorn sculpin, and red hake) and epibenthic invertebrates. One of the most common invertebrate species was the shrimp *Dichelopandalus leptocerus* (Fig. 1). They are 2 to 4 inches long and were found to be widely distributed over the south-central portion of Georges Bank. These and similar photographs provide information about the habits and dispersion of animals that cannot be obtained by conventional sampling methods.

Instrument Development

Russell K. Paul

The design and development of a microminiature sonar transceiver took up several months early this year. Designed by request of Dr. John Zeigler, to be flown in their "Cricket" rocket, the depth sounder had to be about the size of a pack of cigarettes and very light in weight, yet have enough power to accurately plot bottom profiles in water depths to thirty or forty meters. To pack the necessarily complex circuits into this limited space microelectronic digital circuits were used to generate all functions and commands in the transmitting section, while linear integrated circuits made up the receiver section.

Commanded by the transceiver, a miniature FM transmitter designed by Charles Simmons provided a radio link to the beach where auxilliary equipment received a pulse varying in length directly with water depth. Beach equipment to decode the pulse length into digital and graphic displays was designed in concept. The sonar transceiver and FM transmitter were breadboarded just as funding for the program deteriorated, and quick tests were made which showed the design to be sound although the need for more power was indicated.

The major effort this year has been the design and building of a new seismic system controller, or programmer. The new Digital Seismic Control (DSC) (Fig. 1) uses a unique approach to synchronization with the recorder to eliminate all dependence upon those mechanical systems of the PGR which have been at the root of many of the problems. Construction is almost totally with integrated circuits for reliability and compactness, and operation is digital.

Using the 240 Hz precision AC supply of the recorder as an input, the DSC counts individual cycles and decodes the count at half-sweep intervals for any of the twelve normal PGR sweep times. Thus dependence upon the mechanical keys of the PGR is eliminated and perfect synchronization with helix position is assured at all times.

Choosing alternate decodes, depending upon whether edge or center keying is desired, the DSC then counts sweeps to a predetermined key interval from 1 to 100. When the preset total of sweeps is reached a completely electronic key is closed. This "key" can handle virtually any keying requirement, grounding or positive, that is needed for oceanographic devices. Closing time is less than two microseconds, in perfect synchronization, and with absolutely no bounce. The total closure time is variable at will, and may be printed on the chart by switching and logic circuits controlling the output of an internal printing oscillator. Normal keying is not interrupted during this process, although signal recording is.

Signal recording, for a single sweep only, may be delayed from 0 to 99 sweeps after key closure, and is controlled by a very fast microminiature relay. The use of a relay, rather than electronic switching, eliminates consideration of signal levels or attenuation, and the life of the relay is conservatively estimated at several seasons of seismic work. A pulse output is available at the start of every recording sweep for control of external signal conditioning circuitry, or whatever.

The DSC thus completely controls keying and recording, key position and position recording, and eliminates the need for the entire keying, programming and commutator sections of the PGR. Since the DSC has no idea what the PGR is doing, except that operation is synchronized with helix rotation, the keying position may be shifted to any point on the sweep by using the differential on the PGR.

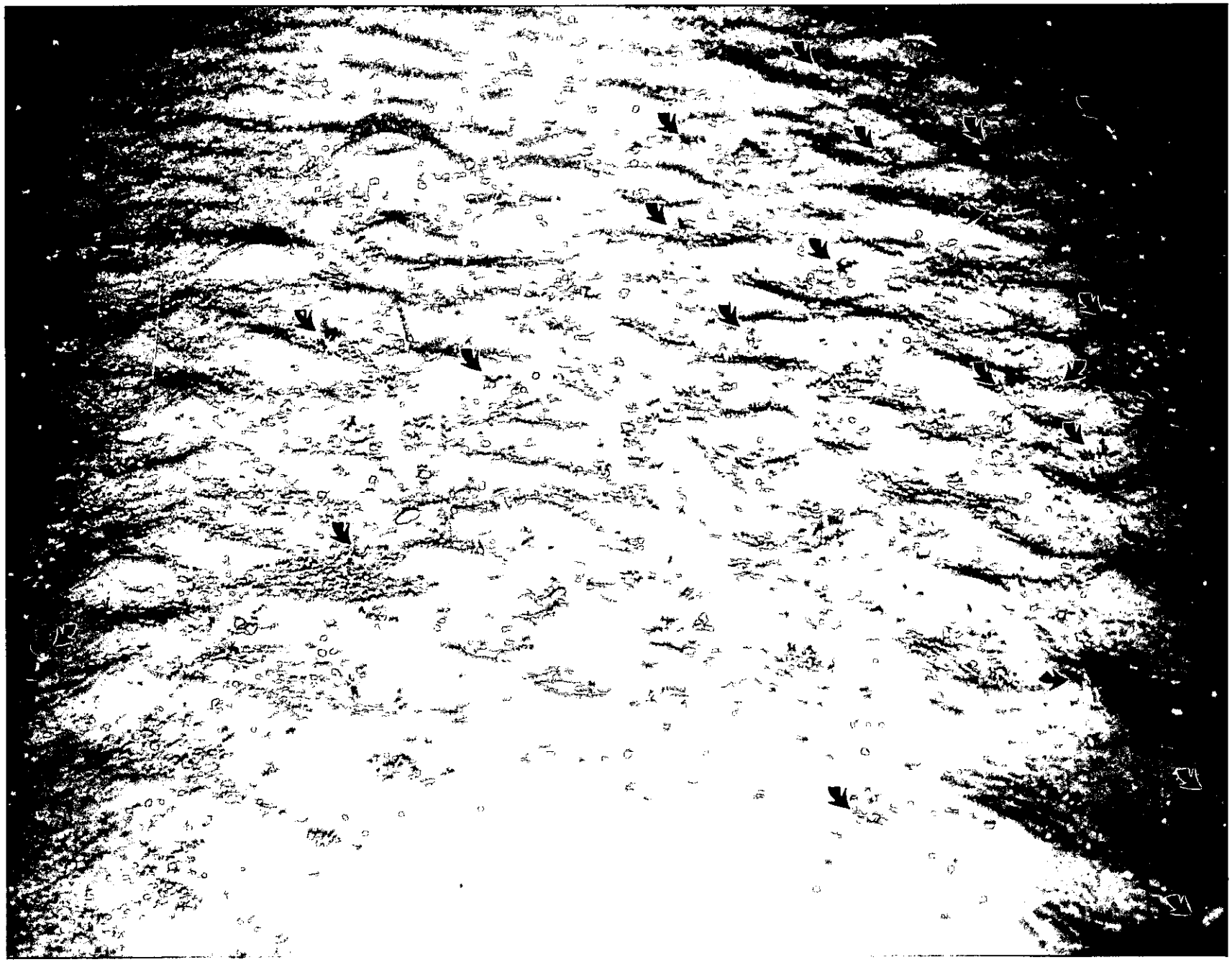
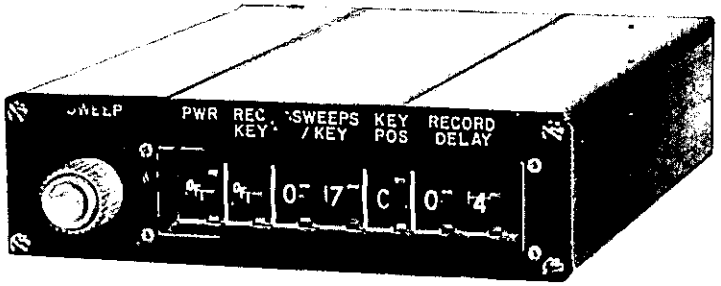
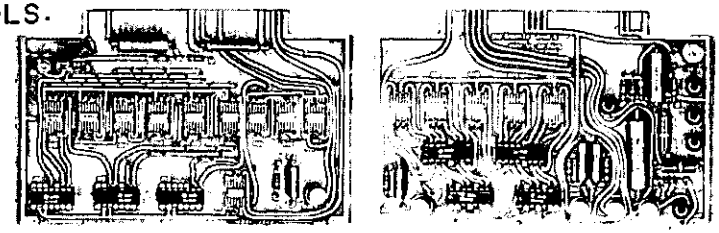


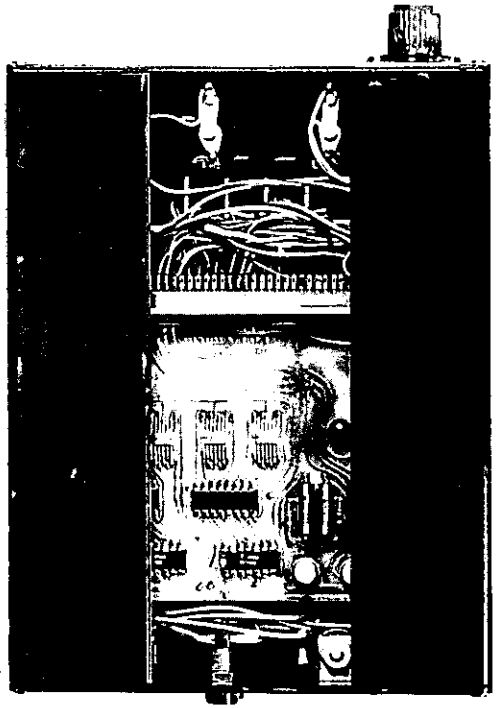
Fig. 1. (Wigley) Pandalid shrimp, *Dichelopandalus leptocerus*, at a depth of 100 meters on Georges Bank.



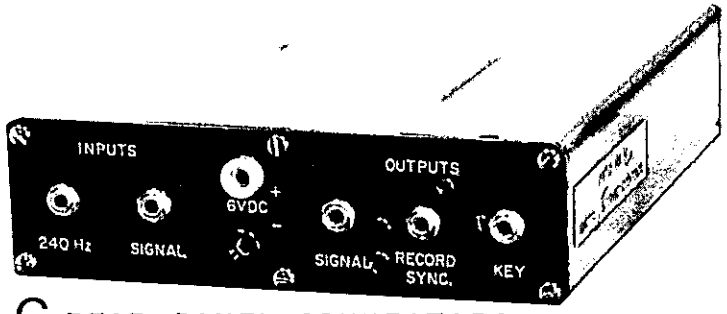
A FRONT PANEL CONTROLS.



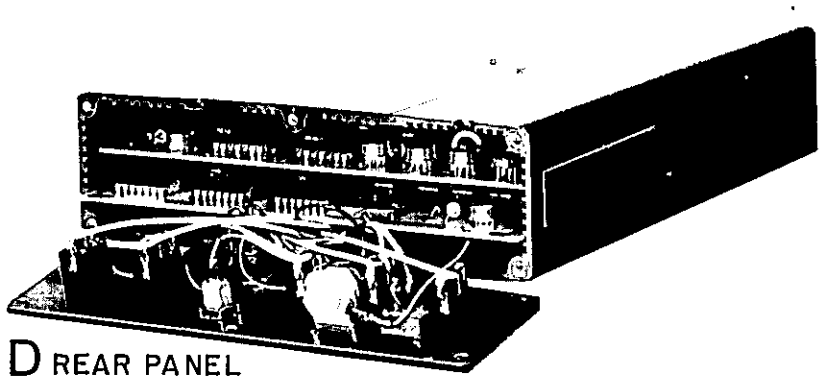
E CIRCUIT BOARDS AND BOARD EXTENDER.



B TOP PANEL REMOVED TO SHOW INTERNAL LAYOUT.



C REAR PANEL CONNECTORS ARROW POINTS TO KEY LENGTH ADJUSTMENT.



D REAR PANEL DROPPED FOR BOARD REMOVAL.

Fig. 1. (Paul) The digital seismic control.

The DSC was designed to control an entire seismic system, and able to take the place of a "master" PGR. As long as the PAC input to the DSC comes from the same source as to the PGRs in the system, synchronization will be perfect. Sound source keying will take place at unvarying intervals, which need not be directly related to the PGR sweep times actually being used, while individual recorders may be run at any sweep and programming desired.

Operation as a simple programmer with recorders other than the PGR is possible by using the recorder key closure as an input after one simple circuit change. This same circuit change also enables the DSC to be used as a predetermining counter with pulse output. The rate of input information may be anything less than ten megahertz, and need not be constant.

Seismic Instrumentation

Kenneth E. Prada

Improvements in instrumentation for seismic applications were made in hydrophone arrays, signal processing equipment, and graphic recording. Design trends have concentrated on size reduction and increased reliability while improving overall performance.

A new hydrophone array was built for use in continental rise studies during July and September. This array is one hundred feet long (30.5 m) and has a continuous diameter of one inch (2.54 cm). The array is divided into four segments of twenty-five feet (7.6 m). Each segment contains fifty crystal bimorph pressure transducers wired in parallel and encased in an oil-filled polyurethane tubing. Segment interconnection is by means of machined aluminum fitting with "O" ring seals. Each segment is independently oil-filled; no oil medium exists between segments, allowing for easy connection and disconnection of the segments for purposes of repair and storage.

The tow end of the array is connected to a two inch (5.2 cm) inside diameter stainless steel preamplifier case. The tail of the array is terminated with a tapered aluminum fitting into which has been potted a nylon tail line.

The array preamplifier is a differential input operational amplifier wired in a common mode non-inverting d-c configuration. The gain is variable from 0 to 40 db and is controllable from the towing vessel by means of an isolated resistance element in the feedback network of the operational amplifier circuit. Frequency response is flat from d-c to 100kHz at full gain and the dynamic range at full gain is 100 db.

The main features of the array are the large number of closely spaced transducers, a small continuous diameter and rugged construction. Its properties of sensitivity, directivity and noise reduction make it an excellent receiver for deep-ocean studies. Its small size and tenacity provide ease of usage, and with care its longevity is assured. Maintenance is simple and takes little time, promising greater quantity of data and less time lost at sea than with previous arrays.

To complement the new array, a system of signal processing was developed with emphasis on compactness and flexibility. A single seven inch rack panel of modular construction can contain up to eight individual solid state chassis for analog signal processing. This sytem was implemented in conjunction with the 200 element streamer during *Chain* cruises 70 and 73. At that time the modular unit contained two array preamplifier control modules, two manual control line amplifiers, a line amplifier with provisions for time variable gain, an adjustable time variable gain control module and a four stage emitter follower module. All of these functions were provided in a package measuring 20" by 18" by 7", including power supplies. Final circuit designs are still under development. When finished, this sytem and others like it can hopefully replace the bulk and mass of equipment necessary in the past.

Through the use of the 200 element streamer and the modular signal processor, excellent CSP records were attained during both cruises. A marked improvement in the quality and quantity of data was realized.

Development of a new graphic recorder is anticipated to be completed by next spring. Emphasis in design is again being placed on compactness and flexibility. In addition to the functions now provided by the PGR, this new unit will feature triggered single sweeps, instantaneous sweep reversal, selection of sweep length in millisecond intervals, dual key outputs with separation variable in milliseconds, a wide range of scale line interval selection, and integrated circuit modular electronic design for reliability and maintenance ease.

ALVIN DIVES

During 1967 the geology group made a total of seven cruises and 17 dives on the Deep Submersible Research Vehicle (DSRV) *Alvin*. The significant operations and results are discussed in the following paragraphs.

Blake Plateau

John D. Milliman, Frank T. Manheim, Richard M. Pratt and E. F. K. Zarudzki

From July 4 to July 13 four dives (numbers 200-203) were made on the inner Blake Plateau, and one (number 204) on the upper continental slope off Cape Hatteras. For use on these dives, a bottom resistivity probe was developed by F. T. Manheim, in collaboration with C. F. Grice, of the Weston Co., marine subsidiary of the Schlumberger Well Survey Corp. The purpose of the probe was to provide a sensitive means of detecting anomalous water resistivities reflecting salinity and/or temperature, both in bottom waters and in pore waters of bottom sediments. When the submarine rested on bottom, the probe's electrodes, which were embedded in a spring-loaded plastic plate, pressed against the sediment. An apparent bottom sediment resistivity could be read inside the submersible through an AC measuring circuit (actually a Schlumberger electronic mud tester).

1. The Blake Plateau dives were located between 31° and 32°N, near the 79th meridian in water depths of 500 to 550 m. An exhaustive bathymetric search was conducted for "*Aluminaut*" hole, a depression in which the *Aluminaut* reported a loss of buoyancy suggesting a possible fresh-water out-flow. No such hole was found. Other depressions, potential sites for present or past ground water discharge, could not be investigated, primarily because of strong currents and rough seas.

The dominant impression on the southwestern portion of the phosphate-manganese pavement area was one of strong north-flowing currents and constant motion of coarse foraminiferal-pteropod sand over the pavement. Occasional large slabs of iron- and manganese-impregnated phosphate also were noted. Temperatures on bottom were 14 to 14.5°C, reflecting the influence of the axis of the Gulf Stream.

At its western margin the manganese pavement gives way to a flat floor of Campanion-Maestrichtian (Upper Cretaceous) limestone. Further west are low hills and mounds of calcareous ooze. The hills apparently grade westward into linear ridges, which previously, on the basis of echo soundings and dredgings, had been designated coral mounds. The ridges trend N-S, have wave lengths 80 to 100 m, heights as great as 50 m, and lengths greater than 1 km. A prolific coral community lives on the ridges; the troughs (between the ridges) are relatively free of living epifauna, but do contain much coral debris, apparently eroded from the ridges.

Currents measured near the western boundary of the manganese pavement were less than 10 cm/sec from the north, with ambient water temperatures of 7°C; this reflects influences of colder slope water. The temporary nature of these currents is suggested by the fact that two days later, during dive 203, the currents a few km to the west flowed from the south with velocities greater than 50 cm/sec.

One dive (202) was cut short by an attack by a 2 m, 90 kg broadbill swordfish (family Xiphidae). The fish wedged his bill into *Alvin*'s outer shell and, unable to free itself, was captured after *Alvin* surfaced. The attacker was later eaten by the crew.

2. The steep slope observed on the continental slope off Cape Hatteras exceeds 70° in places. An apparent outcrop was seen and sampled, but the samples were subsequently lost when the sample rack was accidentally jettisoned. Polychaete worm tubes apparently increase sediment competency on steep slopes.

A multi-layered deep-scattering layer observed in the water column off the continental slope of North Carolina was comprised of layers of squid, myctophid-like fish, and shrimp-like crustaceans. In each layer one type of these three animals seemed overwhelmingly dominant, giving a definite infra-structure to the scattering layer.

Continental Shelf off Chesapeake Bay

K. O. Emery

Two dives on the outer third of the continental shelf off Chesapeake Bay (made with R. L. Edwards, Bureau of Commercial Fisheries, Woods Hole) explored several ridges that rise as much as 10 meters above the intervening flat areas at 50 meters depth. These ridges are probably submerged beaches and dunes similar to those

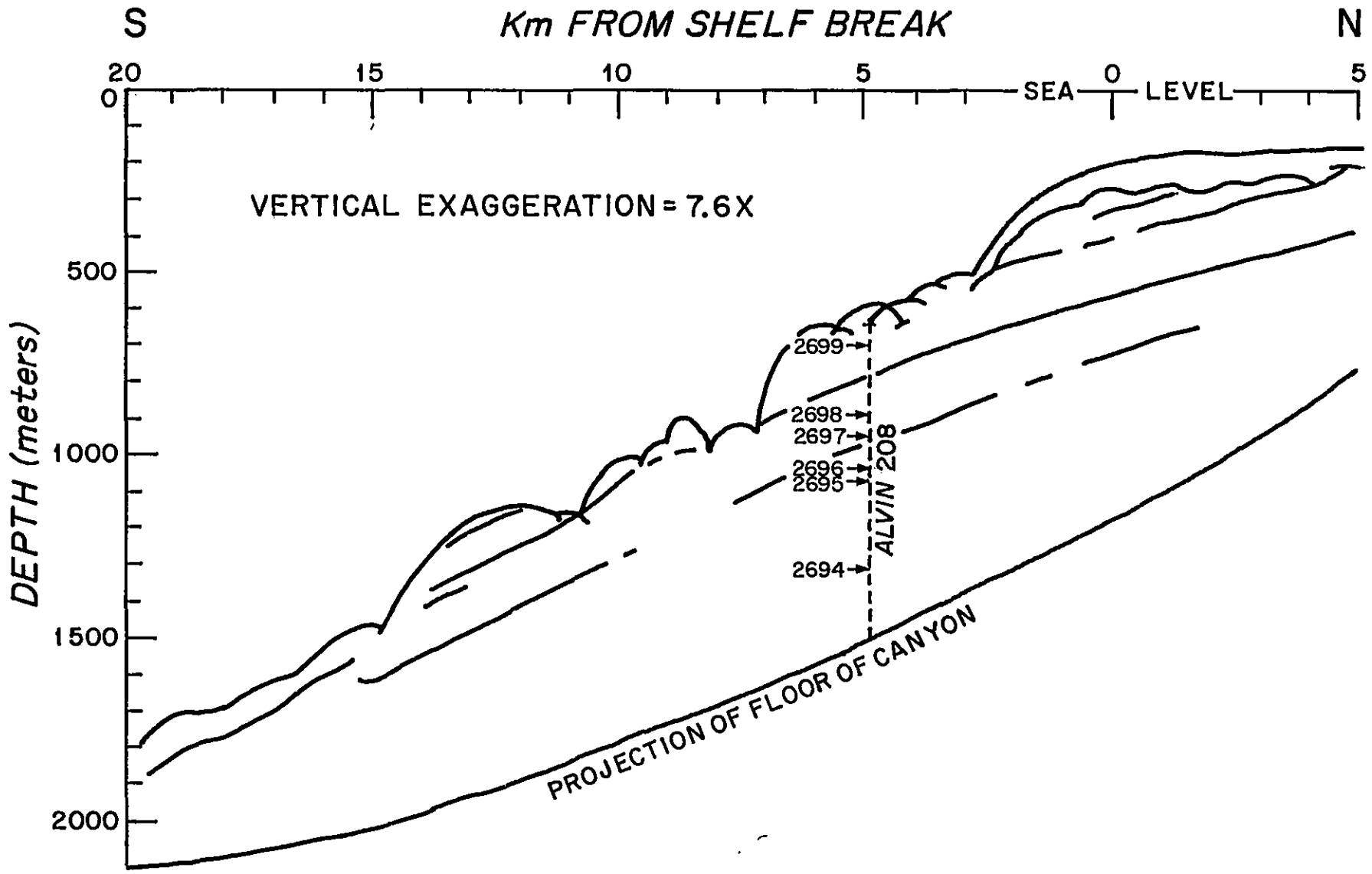


Fig. 1. (Trumbull and Hathaway) Longitudinal section of Oceanographer Canyon projected on seismic profile of nearby continental slope (After Uchupi and Emery, 1967, profile 50). Vertical dimensions have been adjusted for differing travel times in water and sediment.

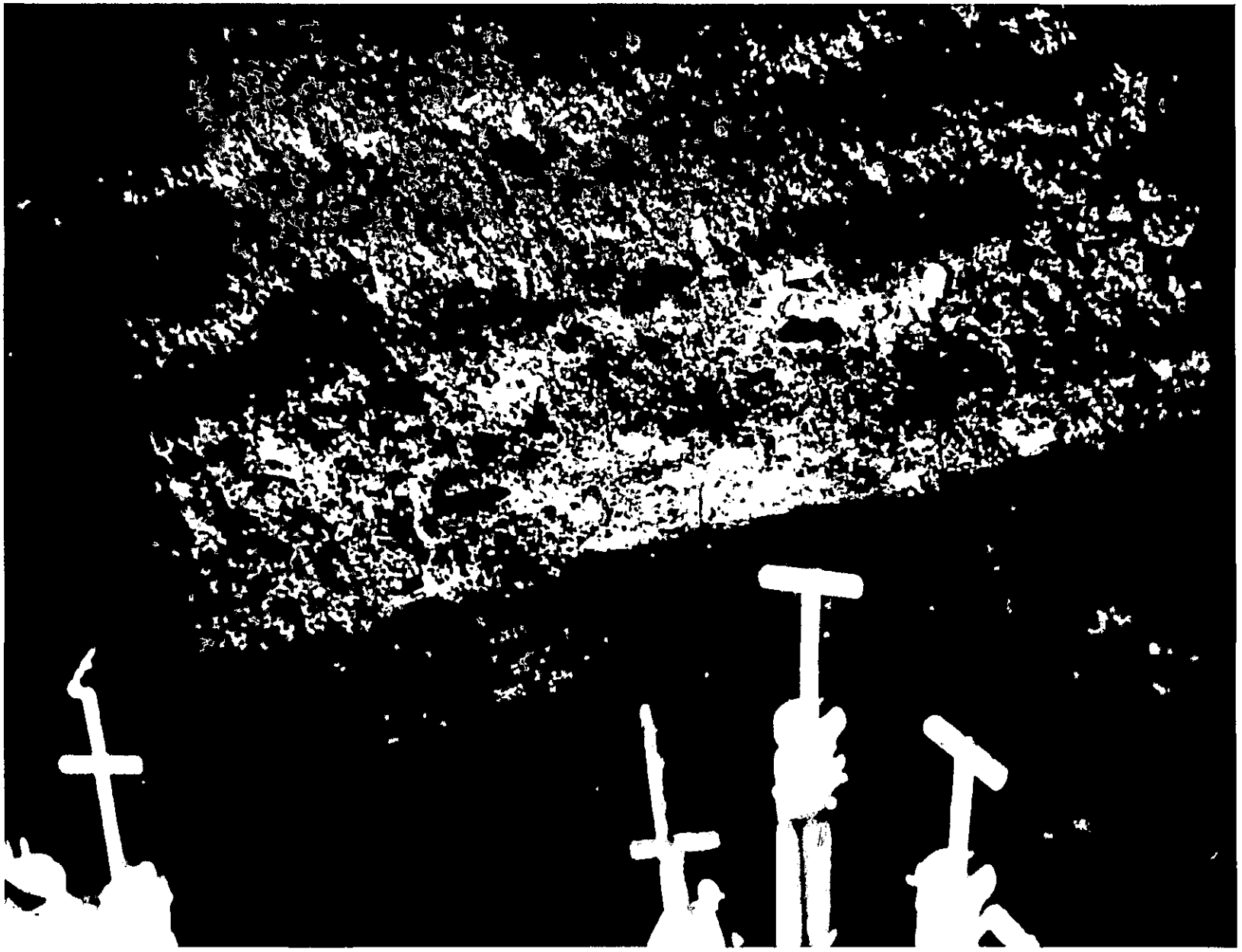


Fig. 2. (Trumbull and Hathaway) Photograph from DSRV *Alvin* showing outcrop of Oligocene chalk at 886 meters in Oceanographer Canyon.

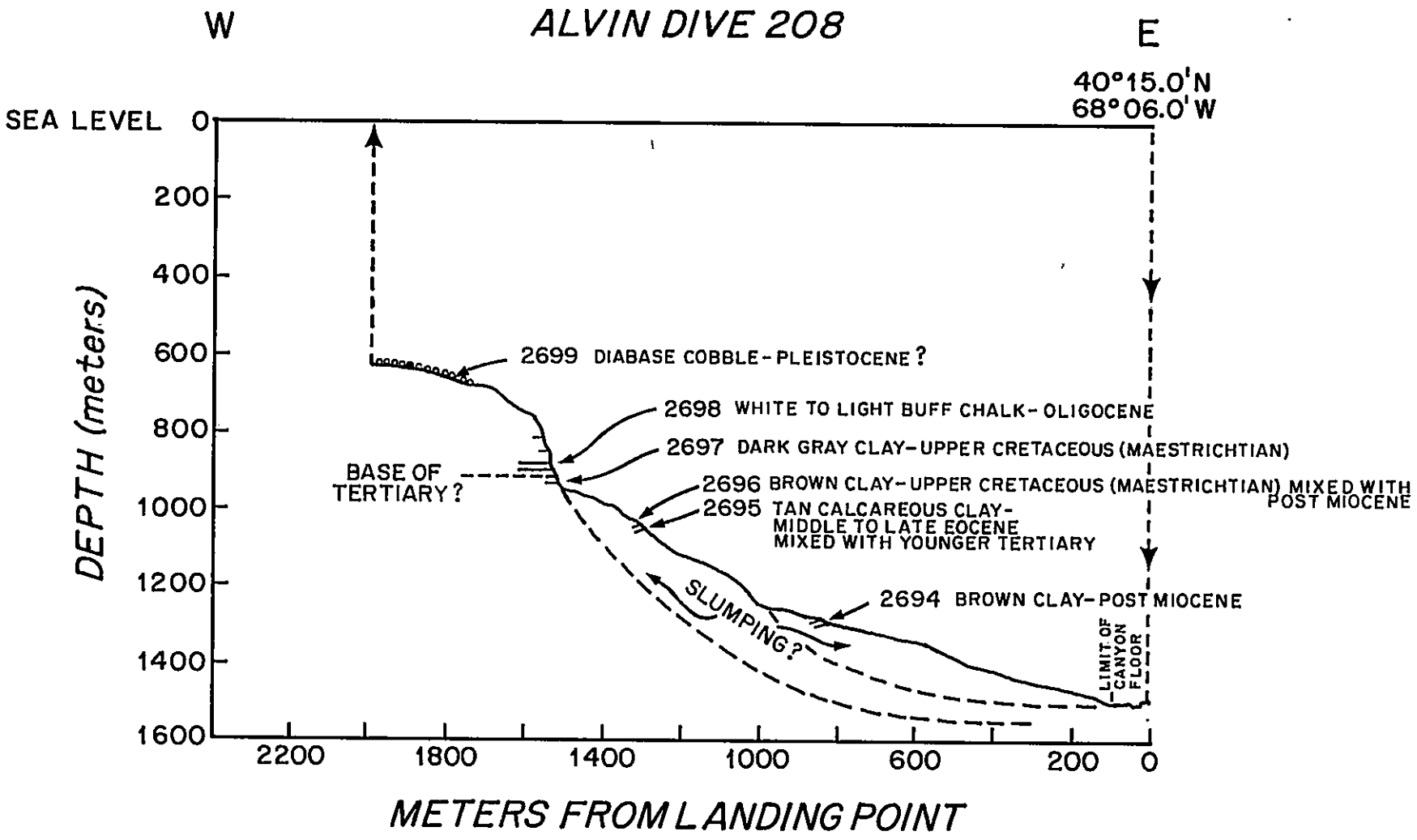


Fig. 3. (Trumbull and Hathaway) Lateral cross section of west wall of Oceanographer Canyon showing location and lithologies and ages of samples collected. No vertical exaggeration.

that fringe Cape Hatteras. The flat areas between the ridges probably are the sites of former shallow-water lagoons and salt marshes. Surface sediments consist of coarse sands of the type considered to be relict from a time of lowered sea level about 15,000 years ago. Submergence of the region beneath the advancing sea merely softened the profiles through some redistribution of sand by currents and by storm waves, whose effect is revealed by large ripple marks on the bottoms shallower than about 40 meters.

Shells of surf clams, ocean quahogs, and sea scallops are locally abundant on the bottom, but about 90 percent of the empty separate valves lie in a concave-up position. Such a position is directly opposite to the hydrodynamically stable position of pelecypod valves on the wave-washed zones of beaches. The concave-down position of 90 percent of the valves on beaches is due to wave wash, whereas their concave-up position on the shelf reflects the absence of effective bottom currents and the role of large benthic animals in reworking and mixing the bottom sediments during the many thousands of years that some of the shells have lain exposed or only slightly buried.

Atop one beach ridge was found a scattered group of oyster shells: the sort of evidence that might be expected to denote the presence of early man on the now-submerged area of the continental shelf. Insufficient time and inadequate tools prevented excavation of the site. At another place atop a ridge two blocks of rock, one about 45 cm long, were noted and collected. Both rocks were igneous, at least 300 km from any reasonable outcrop, but neither of them exhibited evidence of chipping by man. Their transporting agent is unknown: their angular shape and their position atop a sand ridge indicate that they were not brought by streams.

Further Exploration of Oceanographer Canyon

James V. A. Trumbull and John C. Hathaway

In August 1967 two dives, made in Oceanographer Canyon, reached the canyon floor at 1530 and 1480 m at approximately 40°15′N, 68°06′W. The floor was 300 m wide and nearly horizontal. Ripple marks, current crescents, and erosion of slightly consolidated deposits near the canyon floor indicated strong down-canyon currents. Local variations in current velocities were indicated by different local intensities of ripple-marking and biological disturbance and by the fact that on the west side the junction of floor and wall was partially eroded and nearly angular, whereas on the east side the junction was gently rounded. During the dives the current velocity usually did not exceed 0.2 knots, although a peak of 0.5 knots was observed in rough terrain on the canyon wall.

Sedimentation in the canyon is indicated by slightly consolidated deposits lying unconformably on canyon wall bedrock and dipping 15° toward the floor. Undercutting at the base of those deposits indicates subsequent erosion. Considerable erosion is also indicated by a 12-meter escarpment in the middle of the floor that is parallel to the canyon axis. A 3-meter escarpment, transverse to the canyon axis, exposed a mixture of glacial cobbles and clasts of canyon-wall sediment similar to that previously cored from canyon floors. The significance of the latter escarpment is not yet clear.

In detailed profile the western wall is an alternation of nearly vertical bedrock outcrops and slopes of unconsolidated sediment lying at 10 to 30°; the average slope is about 25 to 30°. Above 800 m vertical cliffs are less frequent and the slopes between them lie at only 10 to 15°. Most outcrops, including the vertical faces, have a surface coating of very fine-grained sediment. Above 700 m the slopes are littered with gravel of glacial origin. Many outcrops above roughly 1,100 m were partially encrusted with sponges, branching corals, and similar organisms. At greater depths such organisms were rarer.

Six samples were collected from outcrops on the west wall as shown in Fig. 1. The ages of these samples were determined by Thomas G. Gibson and James F. Mello, U.S. Geological Survey, to be from late Cretaceous to post Miocene. One sample of chalk, No. 2698, was also examined by Joseph E. Hazel, U. S. Geological Survey, and independently by R. M. Goll, Woods Hole Oceanographic Institution and was identified by them as Oligocene in age (Fig. 2). This sample and a sample of Oligocene age from The Gully reported by G. A. Bartlett (1967), of the Bedford Oceanographic Institute, Dartmouth, Nova Scotia, form the only reported occurrences of Oligocene rocks north of Cape Hatteras. A cross section of the wall showing the ages and lithologies of the samples is shown in Fig. 3. The relatively young ages of the lower two samples suggests that slumping has carried Tertiary and younger materials to the canyon floor and covered outcrops of Cretaceous rocks.

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Georges Bank

Roland L. Wigley

A shallow dive was made on the western edge of Georges Bank (41°09′N, 68°43′W) in water depths of 58 to 63 meters. Weather conditions at the surface were excellent; it was bright and clear and the sea was nearly calm. Subsurface conditions were not nearly so favorable. Visibility was limited to about 20 feet, due largely to rather dense concentrations of plankton. Also, moderately strong water currents (up to 1½ knots) and the presence of occasional boulders made it necessary to cruise at very slow speeds along the sea bottom. The bottom was flat, except for the boulders, and was carpeted with clean pebbles. Natural light from the surface provided adequate illumination for seeing the larger, light-colored objects at the bottom although *Alvin's* lights were necessary for detailed viewing.

Fourteen species of groundfish and two species of pelagic fishes were observed. The two most common species were longhorn sculpin *(Myoxocephalus)* and eelpout *(Macrozoarces)*. Two rare species at this locality were a leopard skate *(Raja ocellata)* and a cunner *(Tautoglabrus adspersus)*. Only one community of benthic invertebrates was encountered. The dominant species were: sea scallop *(Placopecten)*, waved whelk *(Buccinum)*, green sea urchin *(Strongylocentrotus)*, northern-heart shell *(Venericardia)*, smooth astarte *(Astarte)*, and encrusting bryozoans *(Ectoprocta)*.

With few exceptions, neither the groundfish nor invertebrates were aggregated; they tended to be randomly distributed over the area. The density of the entire faunal assemblage, however, varied from place to place. The absence of schools of groundfishes and lack of dense aggregations of sessile invertebrates on the plentiful rock surfaces were unexpected.

Based on the operational aspects of the submarine (maneuverability, speed, illumination, etc.) and judging from the ease with which most of the fish could be identified, it appears that a submarine could be used very effectively for taking inventory of the commercial groundfish stocks in the offshore New England region. Also, the larger epibenthic invertebrates, such as sea scallops, green sea urchins, waved whelk, etc., could be quantitatively estimated from a submarine.

Evidence of Deep Strong Current Action in a Submarine Canyon

David A. Ross

On August 31, 1967 I made a dive aboard *Alvin* in the axis of Corsair Canyon (41°17′N, 66°01′W), the northeasternmost member of a series of canyons on the seaward coast of Georges Bank.

The canyon floor, at a depth of 1604 meters, was covered with fine-grained, ripple-marked sediment and several large boulders (averaging about 50 cm in diameter). The boulders were partially covered with sediment and were surrounded by scour marks (Fig. 1a).

An outcrop of relatively resistant rock, forms an overhang on the canyon flank (1577 m) (Fig. 1b). The upper part of this outcrop forms a terrace about 10 meters wide, covered with ripple-marked sediment. Talus material from this outcrop was found at the base of the canyon flank.

The observations in and near the canyon floor definitely show that bottom currents capable of erosion exist at a depth of at least 1600 meters. This conclusion is based on: (1) ripple marks, scour marks, and boulders partially covered with sediment in the canyon axis, and (2) the undercutting of relatively resistant rock and the existence of a ripple-marked terrace approximately 30 meters above the canyon axis. The currents must be intermittent, since some of the boulders have sediment cover. Current direction, as indicated by the scour and ripple marks, is down the canyon axis to the south.

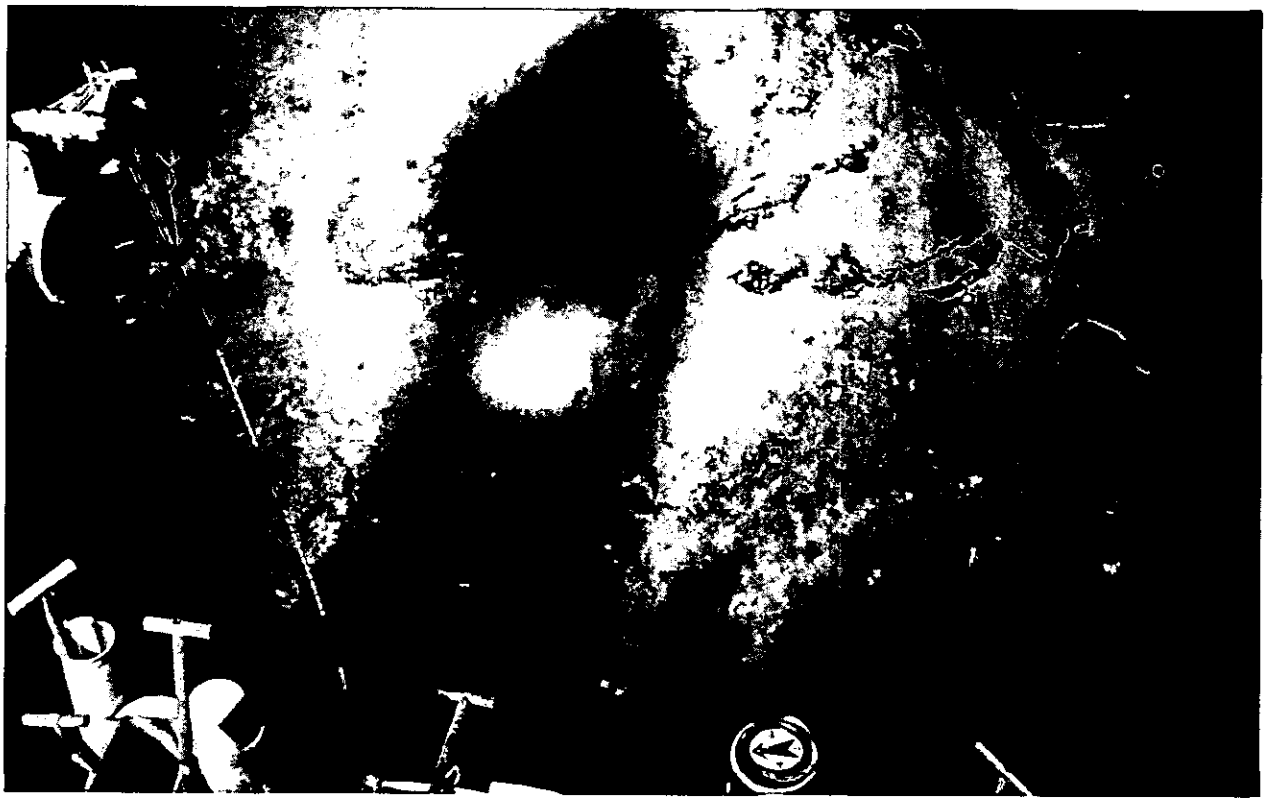

Fig. 1a. (Ross) Large, angular boulders that are partially covered with sediment in the canyon axis. Note large scour mark in the upper right. Shadow in the picture is from the mechanical arm.

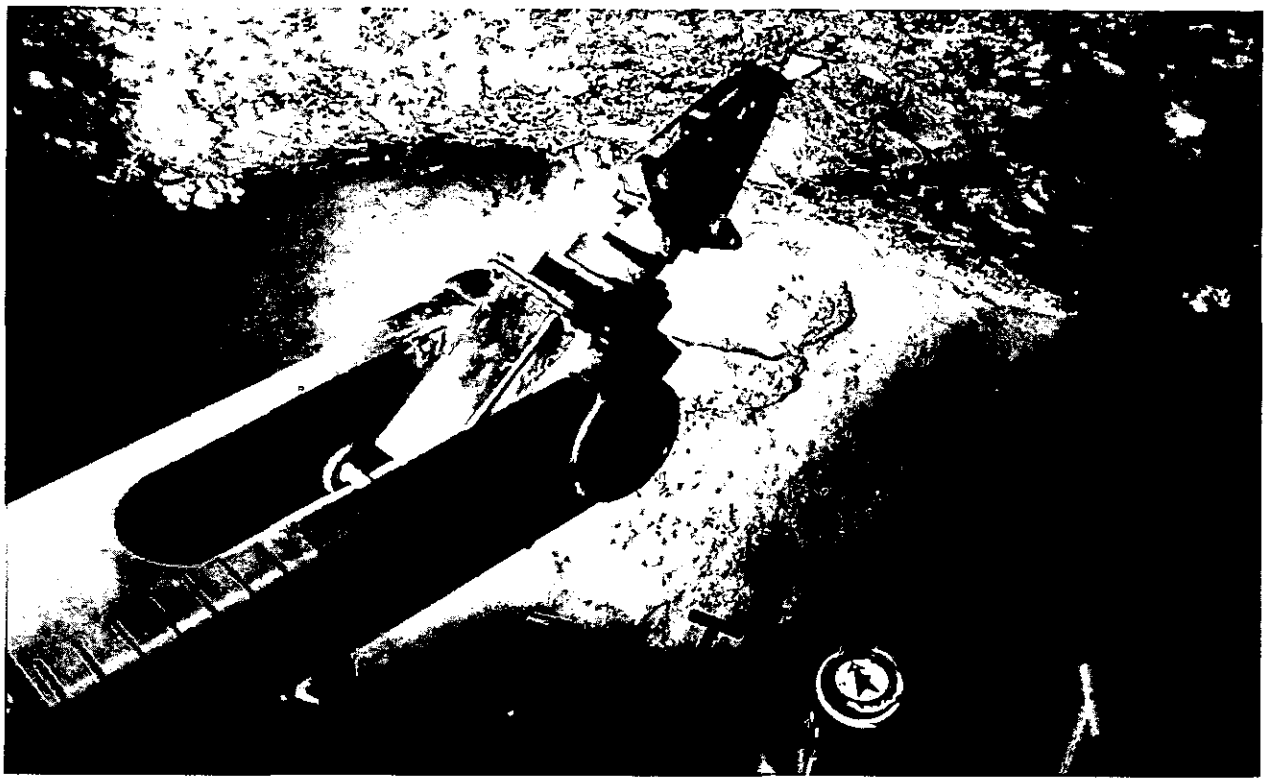

Fig. 1b. (Ross) Outcrop at 1577 meters. Note the overhanging appearance of the outcrop.

Continental Slope South of Martha's Vineyard

K. O. Emery and David A. Ross

Four dives aboard *Alvin* were made at 1300 to 1400 meters on the continental slope south of Martha's Vineyard. These dives were primarily intended to search for the lost arm of *Alvin*, but they permitted the making of many geological observations, measurements, and bottom photographs. Many soundings from the supporting ship, *Crawford*, showed that the area of the dives is a section of a smoothly sloping part of the continental shelf adjacent to a previously known, but unnamed submarine canyon (now termed *Alvin* Canyon). Observations made aboard *Alvin* showed the presence of six ridges 3 to 10 meters high, composed of clayey silt (at their surface at least), and lying at right angles to the bottom current and to the general contours of the continental slope. Three blocks of probably ice-rafted rock were found, all atop the ridges. At present, the origin of the ridges is a mystery; various data and lines of reasoning rule out the possibility of their being rock outcrops, terraces, or depositional features of bottom currents. Possibly they mark one flank of a large landslide that has been invoked to explain the region of deeper than normal continental shelf between Block Island and Martha's Vineyard.

Continental Shelf off Block Island

K. O. Emery

Two dives were made off Newport and off Block Island to check the results of acoustic side-scanner surveys made during 1966. Both the dives and the acoustic surveys were joint undertakings with J. E. Sanders of Hudson Laboratories. Visual observations of the bottom confirmed the acoustic interpretations of flat sandy and boulder bottoms. They also improved the differentiation of rippled sand and gravel bottom on the acoustic records. The dive off Block Island was especially interesting because of the 1.5-knot current that produced considerable saltation of sand grains and migration of sand ripple marks. As expected, the bottom experiencing the greatest tidal current is covered with boulders, some of which are larger than the submersible.

"OCEANEATHER" MAPS, SIMILAR TO WEATHER MAPS, OBSERVED UNDER THE SEA

John C. Beckerle

Data collected on an extensive cruise, *Atlantis II* #22, during the summer of 1966 for the purpose of measuring the temperature and the sound velocity in the waters between Bermuda and the Antilles has been analyzed. This cruise brings the three year-long research program into the sound velocity variations and ocean movements in this ocean region, and into the influence of this ocean region on the circulation of the northwestern Atlantic Ocean to a reasonable point for coordinated presentation of the work. The program also gives insight into the role played by the temporal and spatial variations of sound velocity on acoustical propagation. Only a few salient features of this research effort will be described below.

The cruise covered an area of over 356,000 square miles with the deep sound velocity profiles equally spaced at 65 miles on a rhombic grid. Contours of equal sound velocity were drawn for a number of depths from these data; in particular, a depth of 800 meters was chosen to allow comparison with observations taken in the summer of 1964. The horizontal variations in the sound velocity at 800 meters depth observed in the 1966 data reveal striking additional evidence for the meandering 240-mile wave length internal Rossby wave that was described (Beckerle, *et al.*, 1966) in connection with the sound velocity profiles observed from *Atlantis II* Cruise #11 made in 1964. Moreover, a comparison of the sound velocity contour patterns at 800 meters obtained in 1966 with those taken during the same season in 1964 show similarities which allow one to interpret the changes in the patterns as evidence that the entire ocean area is undergoing a long period horizontal oscillation (mostly in a northwesterly direction). There is some support for this interpretation in other related research. The changes in the contour patterns that are observed remind one of the kind of changes observed on weather maps. Accordingly, we believe that continued sound velocity profile or equivalent measurements over extensive regions of the ocean will eventually produce "oceaneather" maps useful in predicting large scale ocean movements.

Some of the features in the contour patterns observed from the 1966 observations in the Sargasso Sea area can be interpreted as evidence for intense anti-cyclonic eddies, some existing in the deep thermocline region. The patterns of these eddies suggest that some of them may be generated in the region just to the southeast of Silver-bank by the flow established at the eastern side of the Bahama Bank. The observations suggest that the huge eddies eventually break off and move northward being captured and transported westward by the southern side of the meandering Rossby wave near 30°N. Eventually, and perhaps almost periodically, they collide with the Gulf Stream having their energy dispersed. A mechanism something like this was advanced earlier (Beckerle, 1967). These findings are believed to have considerable importance in understanding the circulation of the western North Atlantic.

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STUDIES IN PLANKTONIC FORAMINIFERA

W. A. Berggren

Our studies in micropaleontology and stratigraphy during 1967 have included investigations on fundamental problems associated with various Tertiary geologic boundaries, as well as the initiation of a program of studying the morphology of planktonic Foraminifera by means of the electron scanning microscope.

A boundary implies a limit or extent which is definable by some physical parameter. The boundaries between geologic systems and periods are difficult to recognize on a world-wide basis. They are often vaguely defined or, in some instances, lack the paleontologic criteria which would render their recognition easier in areas far from the region where they are typically defined and developed. A detailed investigation of the criteria which characterize the major geologic boundaries of the Cenozoic Era (the last 65 my) and an attempt to synthesize all available data which will enable stratigraphers to formulate a unified mondial subdivision of the Cenozoic Era has been made this past year. This has involved comparative studies of numerous stratigraphic sections on land (western Europe, North Africa, circum-Mediterranean region, southwest Soviet Union, North and South America) and deep sea cores. The suggested regional biostratigraphic correlations of time-rock units around the world should aid stratigraphers in reaching general agreement and understanding on one of the problems which continues to plague stratigraphy--the question of geologic boundaries. In particular our work would be of considerable aid to future biostratigraphic work in the oceans. With an ever-expanding program of deep-sea coring and continued attempts to unravel the history of our earth as represented by the evolution of marine microorganisms now fossilized in deep-sea sediment, the earth scientist is in a better position to relate these changes to the boundaries of the geologic column.

In a more recently completed investigation several of us (Dr. Phillips, Dr. Wall, Miss A. Bertels, and myself) have been able to present for the first time an absolute age for the Pliocene/Pleistocene boundary based on paleomagnetic and paleontologic studies on deep-sea cores from the south-central North Atlantic. The method is outlined below. Paleontologic criteria characterizing the Pliocene/Pleistocene boundary in the type area (Calabria, Italy) were recently recognized in deep-sea sediments to occur within the Olduvai Normal Event which has been dated at 1.80-1.95 my. Several significant extinctions among planktonic Foraminifera and other organisms are related to this interval. The absolute age of the Olduvai Normal Event comes from the radiometric dates made on lava flows in Olduvai Gorge, Tanzania, with which are associated the earliest proto-hominids described by L. S. B. Leakey. Thus we are able to present a schematic diagram showing the relationship between the evolution of marine microfossils and early Man within the time framework of the Pleistocene epoch. As has been suggested in the past, Man is a child of the Quaternary, and the Quaternary, indeed, the Age of Man.

A final phase of our investigations here at Woods Hole has been the joint program with Professor S. Honjo, Department of Geology, University of Hokkaido, Sapporo, Japan, on electron scanning microscopic studies of the

shell morphology of planktonic Foraminifera. With a depth of field penetration heretofore impossible by conventional light microscopic and normal photographic techniques, we have been able to observe details of surficial morphology which have opened up an entire new era of paleontologic investigations.

TECTONICS OF MID-OCEAN RISES

Carl Bowin

The Mid-Atlantic and Carlsberg ridges have rough topography with local relief of 500-1500 meters. A median rift valley can usually be distinguished. The mid-ocean rises of the Pacific and Antarctic, on the other hand, have smooth topography with local relief of 100-500 meters and lack a median valley. The occurrence of metamorphosed rocks (greenstones) has been documented from the Mid-Atlantic Ridge at 22°N (Melson *et al.*, 1966) and also from the Carlsberg Ridge in the Indian Ocean at 5°N (Cann and Vine, 1966). Peridotites and serpentinites have been obtained from the Mid-Atlantic and Carlsberg ridges (Chernysheva and Bezrukov, 1966). As yet, such rocks have not been recovered from the continuation of the oceanic rise system in the southern and eastern Pacific Ocean.

A few years ago, the smooth topography and absence of a median valley were believed to indicate a youthful age for the East Pacific Rise, which, in time, was expected to develop the topography shown by the Mid-Atlantic and Carlsberg ridges. Magnetic profiles of mid-ocean rises, when interpreted in the light of the concept of sea-floor spreading (Hess, 1962) and alternating normally and reversely magnetized strips of crust (Vine and Matthews, 1963) suggest that almost all parts of the oceanic rise system are contemporaneous and currently active (Vine, 1966). The length of time during which individual segments of the system have been active appears to be related to the total width of the feature and not to the roughness of the topography.

Slow spreading rates (1.0 to 1.5 cm/yr) characterize the Carlsberg Ridge, the South Atlantic Ridge, the Reykjanes Ridge, and the North Atlantic Ridge. The Gorda Ridge in the northeastern Pacific has a median valley and a spreading rate of about 1.0 cm/yr. On the other hand, the Pacific and Antarctic ridges (excepting the Gorda Ridge) have higher spreading rates (2.9 to greater than 5.0 cm/yr). Menard (1967) has independently noted this relation of spreading rate and rise topography. The most remarkable degree of magnetic symmetry so far observed has been noted across the Pacific-Antarctic rise, where the rate of spreading appears to be about 4.4 cm/yr (Pitman and Heirtzler, 1966).

Since it seems most probable at present that the oceanic ridge systems that give evidence for sea-floor spreading have a similar genesis, the large topographic differences between parts of the world rift system probably indicate behavioral differences of only the shallow levels of the crust and upper mantle. The rocks at the sea floor no doubt undergo brittle fracture, whereas the rocks at greater depths undergo ductile flow. The thickness of the material that deforms by brittle adjustments may determine the behavior of the surficial rocks and hence, the topography. Where this material is thin, it may separate along vertical fractures filled in by new intrusions of basic magma. Where this material is thicker, vertical fractures at depth may change to normal faulting and rifting in the upper levels. The inclined faults give rise to sinking of the central rift and uplift of the bordering parts because of the wedge shape of the crustal blocks. Lava flows appear commonly to partly fill the central rift. Older flows occur on the inward flanks of the ridges bordering the rift, and they were probably exposed through uplift and faulting as they were transported laterally away from the central rift. The magnitude of the rifting and uplift is probably limited by the thickness of the brittle material, by isostatic compensation of parts of the crust that are greater in horizontal dimension than about 40 km, and possibly by gravity sliding and slumping on the side of the ridges away from the central rift.

Material that deforms by brittle fracture may be thin at sites of fast spreading because high rock temperatures might occur at shallow depths. This situation might account for the correlation of rifting and rougher topography where spreading rates are less than 2.0 to 2.5 cm/yr and the occurrence of less extensive surficial structural rearrangement where spreading rates exceed these values.

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SEISMIC REFRACTION MEASUREMENTS IN THE BALTIC SEA

Elizabeth T. Bunce

Seismic refraction measurements were made in two areas of the Baltic Sea in June 1967 (Fig. 1). The refraction data were obtained in the course of the transmission measurements program of MILOC BALTIC 67.

Three end-to-end profiles 10 to 14 km long were obtained, two in the area south of Öland Island, Sweden, the third to the east, north of the peninsula of Hel, Poland. The water depths vary from 60 to 90 meters between the areas.

The receiving positions for the two profiles south of Öland Island are only 46 km apart but the structures differ markedly. The northern section, only 500 m thick, shows a rather thin sedimentary cover above 350 m of 3.7 km/sec material that in turn overlies 5.6 - 5.9 km/sec velocity material. The southern section, almost 2 km thick, has an equivalent amount of low velocity material, and a layer about 1 km thick having velocity 4.8 km/sec that overlies 6.0 km/sec velocity material. The eastern profile shows high velocity material, 5.6 km/sec, at 2.5 km depth.

Correlation of the layers determined by seismic refraction with nearby geology suggests that the structural change south of Öland Island may represent the boundary of the Sarmatian Shield in this region.

STRUCTURE OF THE LESSER ANTILLEAN ARC

E. T. Bunce, C. O. Bowin and R. L. Chase

During October to December 1967 five geophysical sections, each including profiles of continuous seismic reflection, magnetics, and gravity were made across the Lesser Antillean Arc, spaced about 200 kilometers apart, extending from west of the Aves Ridge to east of the Puerto Rico Trench or Barbados Ridge (Fig. 1).

The Aves Swell is a broad feature composed of both a broad swell and ridges of opaque material covered by 0 to 1.6 seconds of layered sedimentary material. The ridges generally occur on the western flank of Aves Swell, but in the south where the swell is wider they occur on both the east and west flanks. Weathered volcanic rock was dredged from a rugged ridge on the west flank of the northern end of Aves Swell.

The Grenada Basin lies between the southern part of the Aves Swell and the Lesser Antilles. The basin contains at least 1.5 seconds of flat lying sedimentary material, which laps up over sedimentary material on the east flank of the Aves Swell and possibly on the west flank of the Lesser Antilles Bank.

A topographically low area lying between the north part of the Aves Swell and the Lesser Antilles Bank is underlain by a disturbed sedimentary sequence continuous with that on the Aves Swell.

Two of the profiles show oceanic sediments and basement dipping beneath translucent material constituting the outer eastern flank of the Antillean Arc. The belt of translucent material ranges from 70 to 140 kilometers wide and lacks coherent internal reflectors.

The relation of gravity and magnetic anomalies to the structure of the Lesser Antillean Arc is being studied.

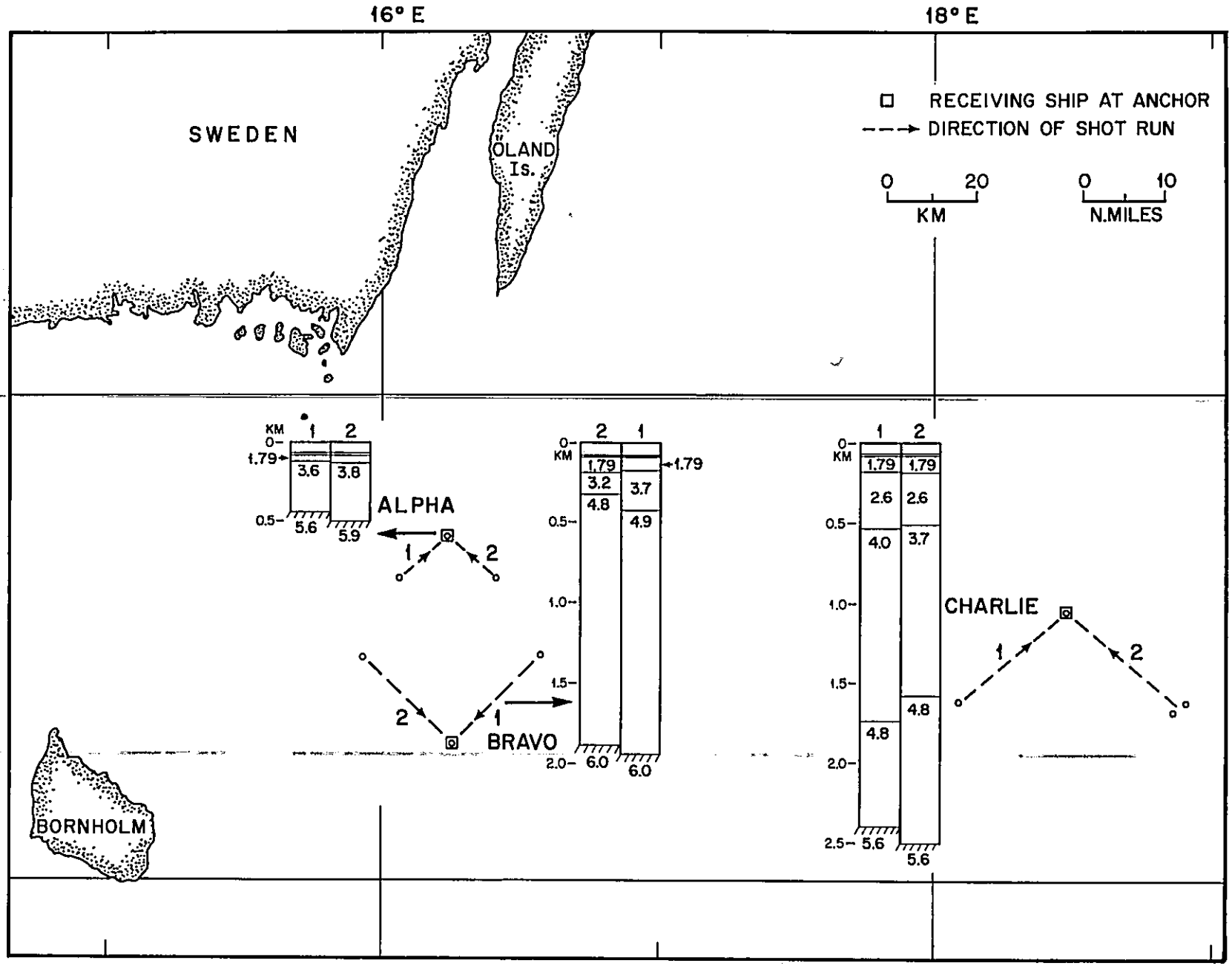

Fig. 1. (Bunce) Location of profiles showing structure sections in the Baltic, velocities in km/sec, layer depths in km.

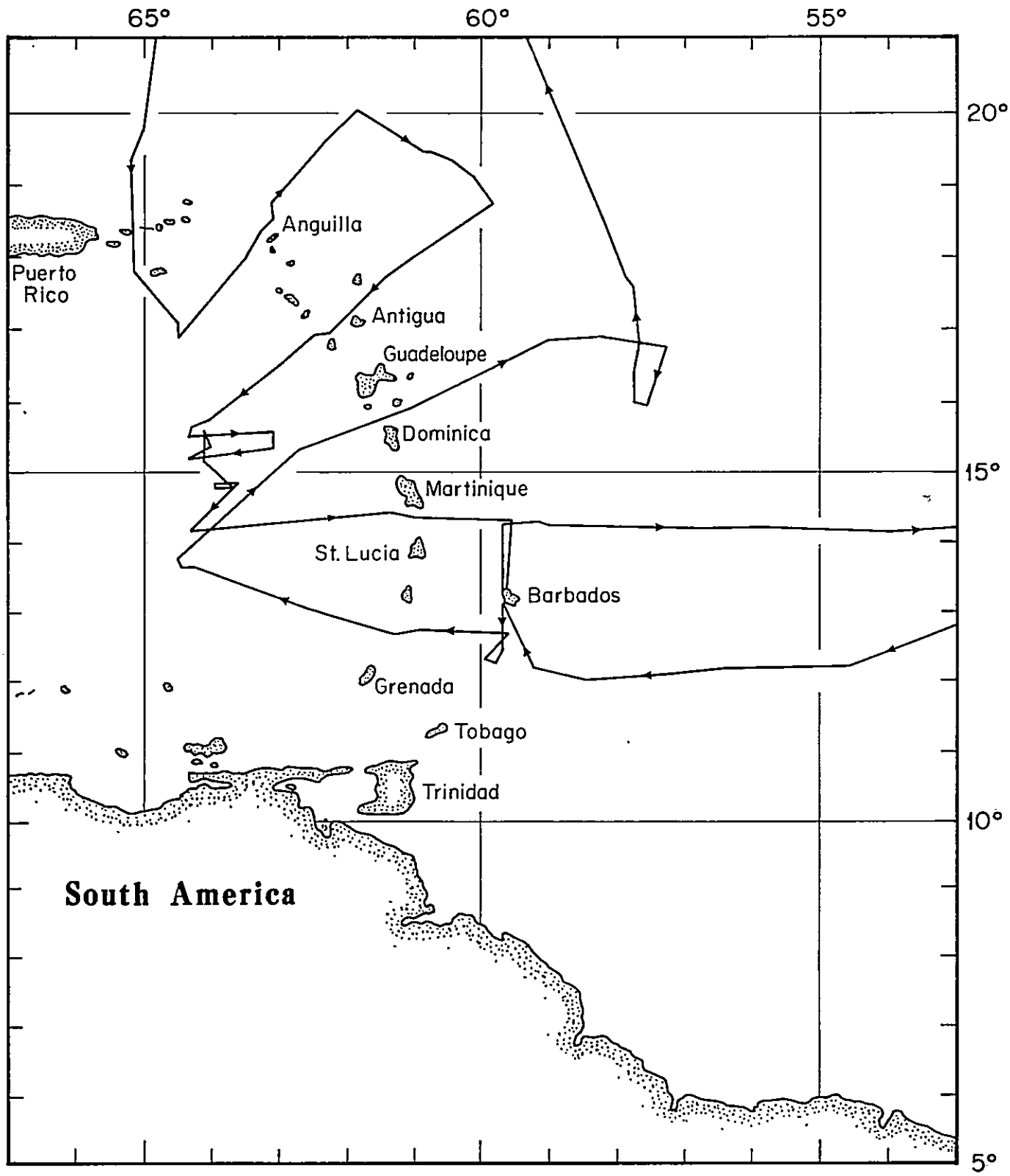

Fig. 1. (Bunce, Bowin and Chase) Chart showing tracks crossing Lesser Antillean Island Arc, *Chain* Cruise 75.

THOLEIITE FROM THE AXIAL TROUGH OF THE RED SEA

Richard L. Chase

Fragments of black glass and partly crystalline volcanic rock were raised in cores from the deeper parts of the Red Sea (named the axial trough by Drake and Girdler, 1964) during *Chain* cruise 61 in 1966. Emission spectrometer analysis by Dr. Frank Manheim of two of the rocks shows that one is a quartz tholeiite and the other an olivine tholeiite. The rocks are low in potassium (K_2O 0.19 and 0.20 weight percent). The potassium content is similar to that of tholeiitic basalt from mid-oceanic ridges and about half that of oceanic-island and continental tholeiitic basalts (Chayes, 1966). The discovery of basalts chemically similar to basalts of mid-oceanic ridges in the axial trough of the Red Sea adds petrologic evidence to tectonic and geophysical evidence (summarized by Girdler, 1966 and Laughton, 1966) adduced to support the hypothesis that the Red Sea is the locus of a "mid-oceanic" ridge, from which the crustal blocks of Arabia and Africa are being transported apart.

The basalt fragments were beneath and interbedded with sub-Recent foraminiferal sediments (Berggren, personal communication), suggesting that they were extruded in the last 20,000 years.

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GEOPHYSICAL INVESTIGATION OF THE CONTINENTAL RISE: *CHAIN* CRUISE 70 AND 73

K. O. Emery, E. Uchupi, E. T. Bunce and S. T. Knott

A synoptic geophysical investigation of the continental rise from the Laurentian Channel area to Cape Hatteras was accomplished during two cruises of *Chain* in July and September. The purpose and background of this investigation relates to the correlation of continuous seismic profiles from the Department of Geology and Geophysics with stratigraphic information from dredgings, piston cores, JOIDES holes off Florida (JOIDES, 1965), oil wells ashore (Maher, 1965), and seismic refraction velocities. These velocity determinations provide good information about the regional variation in thickness of Tertiary strata inshore of the continental rise (Emery, 1967). Continuous seismic profiles made earlier indicate the presence of another and nearly separate mass of sediment beneath the continental rise, but few of the profiles extend more than 50 km onto the continental rise. Since the sediments of the continental rise lap onto Upper Cretaceous strata of the continental slope and lie above the Upper Cretaceous Horizon 'A' as described by J. Ewing *et al.* (1966), the major part of the continental rise off eastern North America appears to be post-Cretaceous in age.

Continental rises are the largest sedimentary depositional units of the world. They are related in some presently unknown manner to the growth of continents (Hess, 1962; Dietz, 1963). Most marine geologists have believed the continental rise to be a depositional feature akin to coalesced alluvial fans ashore, but deposited largely by turbidity currents. Recently Heezen, *et al.* (1966) presented the hypothesis that the rise may owe its shape to redistribution of sediments by currents that flow parallel to the bottom contours. Information about the source, direction of movement, and places of deposition of the coarse-grained components may be obtainable from continuous seismic profiles made over a large region.

Geological literature also contains much speculation about the rates of erosion of the continents, based chiefly upon the annual load of suspended sediments discharged by streams. These data at best are known only poorly, and so attempts have been made to supplement them with estimates of the volume of sediment deposited on the sea floor during a given time interval (Gilluly, 1964). The estimated volume of 100,000 km^3 of post-Cretaceous sediment computed from Hoskins's (1967) isopach contours from the top of the continental rise is based on better data than

are previous estimates of post-Cretaceous sediment volumes in comparable areas. This volume corresponds to an average rate of deposition on the continental margin of 0.8 cm per thousand years. However, there are two deficiencies in the information: (1) how much of the sediment is detrital and how much is biogenic, remains unknown, and (2) how much sediment in the continental rise lies seaward of the present limits of the seismic profiles? The first may be remedied to some extent by analyses presently being made of the composition of dredge, core, and drill samples. The second requires making a more extensive seismic survey than has so far been made of a continental rise.

About 8,000 kilometers of continuous profiles of bathymetric, seismic reflection, gravity, and magnetic measurements were obtained on the two three-week cruises (Fig. 1). Data from which compressional wave velocities of the sediments can be derived were obtained at intervals along the track by use of expendable sonobuoys.

Several noteworthy improvements in profiling technique were made during this work. The signal-to-noise ratio of the seismic reflections was improved in the following ways: by use of arrays that approach a continuous sensor configuration (the so-called streamers); by summation of the outputs of two or more simultaneously towed arrays; by simultaneous use of two sources, and by use of multiple electrode arrays for the underwater spark to increase output energy. In addition, sonobuoys were used to receive reflected and refracted signals from the sea floor and sediments beneath it.

The "streamer" array used as sensor (Prada, 1967) is a modified version of an array called the "garden hose" used on the west coast of the United States by the U. S. Geological Survey and others. The Woods Hole modification approaches a continuous line configuration for there are 200 elements in the 100 foot array.

A preliminary examination of the data shows good correlation between the new information and that already available, although all of the profiles have not been examined in detail. Basement structure and the family of reflectors related to Horizon 'A' were traced under the rise and slope with tentative ties to on-shore well data and to refraction determinations from studies made earlier on several locations on the shelf. Generally, the composite of reflectors making up Horizon 'A' and the sediments above and below it are flat-lying, suggesting that the rise from Nova Scotia to Cape Hatteras has been stable since pre-Cretaceous time. Abyssal hills on the Hudson Fan appear to result from down-slope slipping of material, possibly of Pleistocene and later age. Underlying shallow sediments nearer the shore are other earlier similarly slumped structures. Reflections from basement structure are observed at as much as 3.5 seconds reflection time below the sea floor of the rise. Preliminary correlations of the seismic profiles with gravity and magnetic observations indicate that some of the unusual internal relief observed in the structure of the rise off Nova Scotia may be due to sediment slumping rather than to intrusion.

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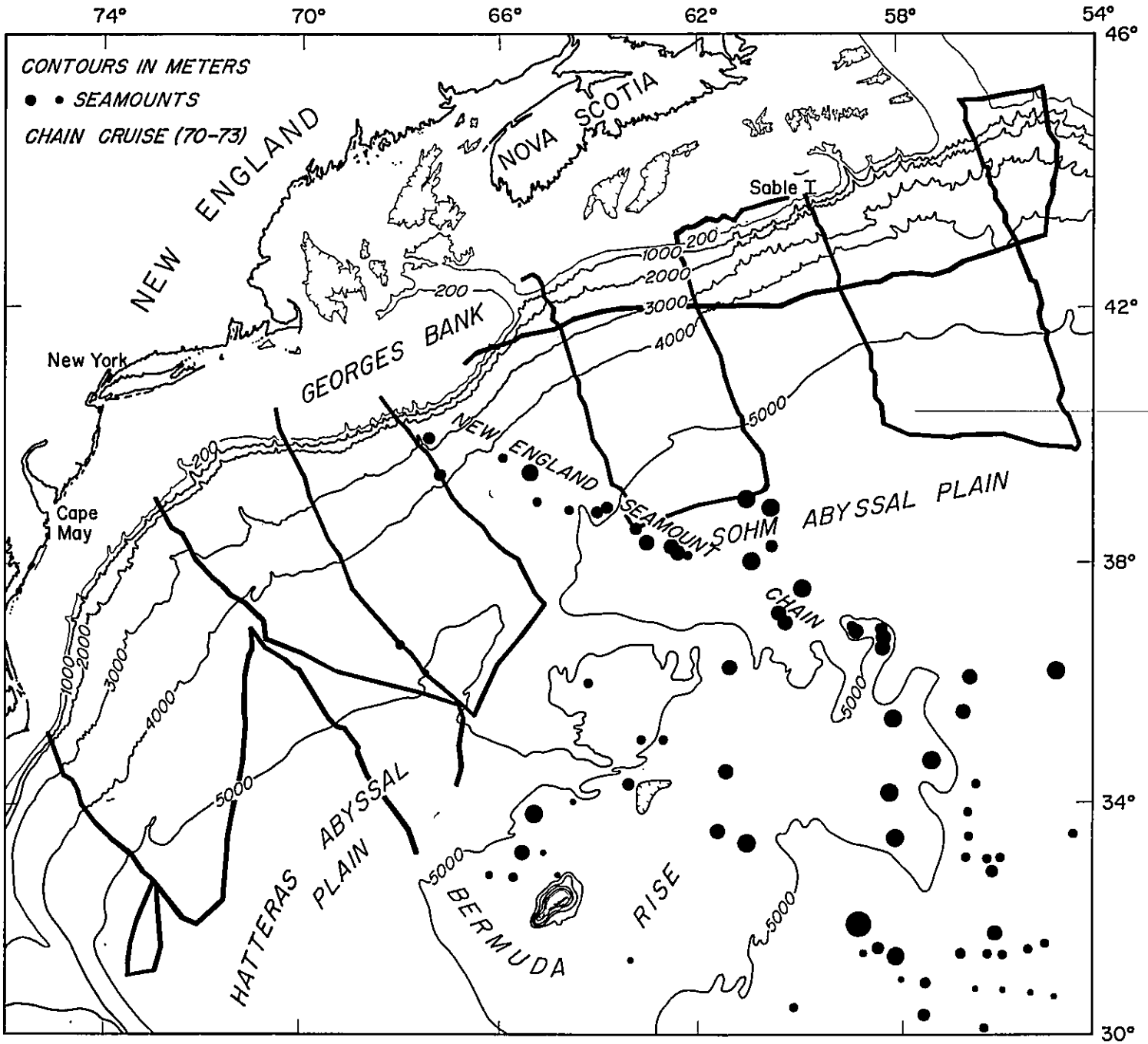

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SHALLOW-WATER SOUND TRANSMISSION IN THE BALTIC SEA

E. E. Hays, L. Baxter II, E. L. Murphy and S. W. Bergstrom

In the spring, in the southern Baltic in water depths of approximately 100 meters, surface warmed isohaline water from land drainage (approx. 7.5‰) floating on top of 10‰ to 13‰ water formed by influx from the North Sea produces a very strong sound refraction channel with a velocity minimum at approximately 50 meters. The relatively smooth sound velocity variation of about 2% in a water depth one-twentieth of the deep sea is about 2/3 of that found in the Sargasso Sea.

The shallow depth of the water combined with the strong sound channel conditions is a rarely studied phenomenon which models, to some extent, in the normal acoustic range, effects which might be found in the deep ocean at subacoustic frequencies, and differs considerably from the conditions of the classical normal mode studies of Pekeris.

In the MILOC Baltic experiments in June, transmission measurements with sparks and explosive charges were made over six different paths extending from nearly zero range to twenty miles with simultaneous coverage of oceanographic and other environmental conditions by a fleet of research vessels. Five hydrophones uniformly spaced in the water column were used to detect the signals.

We are investigating the variation with frequency (in the range of 50 to 8000 Hz), of the transmission loss and the dispersion in the arrival time, as a function of depth. Some sound spectrograms (intensity plotted on coordinates of frequency versus arrival time) were made during the experiment. In our analysis of the tape recordings we have been completing the set of spectrograms and organizing them in terms of location, range, and hydrophone depth. In addition we are measuring by analog computer the spectral energy at 100 Hz, 3500 Hz, and 8000 Hz as a function of range and depth.

In the sound spectrograms we find pronounced dispersion extending to frequencies as high as 800 to 1000 Hz. Somewhat unusual features of these records are the relatively early arrival of some of the frequencies in the range between the Airy phase and the water wave, and the absence of distinct or separate mode curves. The characteristics of these spectrograms vary smoothly and consistently as a function of hydrophone depth with the water wave being relatively stronger in the hydrophones that are located near the channel axis.

Results of a preliminary modal analysis based on closed form solutions with simplified boundary conditions do exhibit some of the observed features. For example, the analysis predicts the trapping of lower modes for frequencies above 1000 cps; the calculated dispersion is of the order of magnitude observed. The analysis also indicates that the early arrival of some of the lower frequencies may be a consequence of the shape of the sound velocity profile in the water column.

UNDERWAY SEISMIC REFLECTION AND REFRACTION PROFILING

F. R. Hess, S. T. Knott and E. T. Bunce

During *Chain* cruises #70 and 73 a system for obtaining seismic oblique reflection and refraction measurements was tested and put to use. The system utilizes expendable radio sonobuoys dropped from the ship as seismic signal receivers, simultaneously with the usual means of continuous seismic profiling (CSP). Oblique reflection and refraction profiles of up to 20 miles extent were successfully obtained, although 12-15 miles range was more common. The system consists of: (1) the seismic profiling sound source; (2) a towed hydrophone array for CSP, (3) military type SSQ-41A sonobuoys; and (4) suitable radio receiver and graphic and magnetic tape recorders. Good refraction arrivals were received in water depths ranging from 40 meters on the shelf to over 4500 meters on the Sohm Abyssal Plain. Preliminary measurements show that refracted arrivals were received from deep structures having apparent compressional wave velocities of up to 4.5 km/sec.

OCEANIC FRONT STUDY

Eli J. Katz

The frontal activity in the Sargasso Sea was again the object of study. In May 1967 a segment of a front was identified near 30°N - 70°W and mapped for 100 nm between two stratified surface layers. The slope of the front and its curvature, as well as a computed geostrophic surface current, were found to be comparable to an earlier observation in the same area of a front between two mixed surface layers (Voorhis and Hersey, 1964). The movement of the front was mapped and yielded a maximum estimated speed of 0.08 knots to the SW, averaged over a four day period.

Hydrographic stations, with an STD apparatus, were made across the front. The nearly continuous record of temperature and salinity obtained during the lowering of this system proved particularly valuable in comparing T-S correlations of the waters on either side of the shallow front.

The T-S diagrams for waters warmer than 19.0°C consisted of two divergent branches, distinguishing the 'northern' from the 'southern' surface waters (Fig. 1a). In lowerings which cut across the front, the T-S relationship jumped discontinuously from one branch to the other and it was therefore concluded that no significant layer of mixed water was to be found at the interface. Below the front, and spreading in both directions, a pool of mixed water was suggested with the water properties of the branch point. It is thought that the mixed layer resulted from drainage down the warm side of the interface of those waters which necessarily mix along the line of contact. These features, and a well-documented tongue of northern water which consistently protruded into southern waters, make up the cross-section of the front as it is shown in Fig. 1b.

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ACOUSTIC TRANSMISSION IN A NON-LAYERED MEDIUM

Eli Katz, James Doutt, and Robert Brockhurst

Computer programs were partially written to do ray tracing and spreading loss computation in the presence of variations of the sound velocity profile with range. The objective is threefold: (1) To perform parametric numerical experiments to predict the qualitative importance of range variations in models of known conditions. (2) To have the capability of converting oceanographic data obtained during an acoustic experiment to acoustic energy predictions, as an aid to analysis and interpretation of data. (3) To study the equivalence of different numerical techniques which have been brought to bear on this general problem in the last few years.

Two distinct ray trace programs were completed. The first employs the Runga-Kutta method to do ray tracing in a field where the velocity is everywhere specified by an input function. Given velocity field, the approximation is in the solution of the eikonal equation. This program is particularly suited for studies of type (1). The second is an extension of the linear gradient technique to another dimension. The approximation is in the specification of the field at intermediate points, the ray path solutions then being exact. Its input is in the form of station data and will be used for (2). Comparison studies between the two will provide perhaps the first contribution towards (3).

The first use of the former program was to examine the published results of Eliseevnin (1965). The paper presented a ray trace picture for a medium described by an Epstein sound velocity profile modified for a sound channel axis which varied with range according to the hyperbolic tangent function. It was determined that a co-ordinate of his figure was significantly mislabeled. This, combined with the exaggerated sound velocity profile, gave a grossly misleading impression of the effect on sound propagation due to range variations in the sound velocity.

A Gulf Stream section was modeled with an asymmetric Epstein profile. The hyperbolic tangent behavior of the channel axis with range was retained, when it was confirmed that this is a remarkably good approximation. Ray trace diagrams were then generated and the overall result was that the change in profile across the Gulf Stream is so gradual that the main results could be simply interpreted as a transformation of the rectangular co-ordinate system to a curvilinear system along the displaced axis.

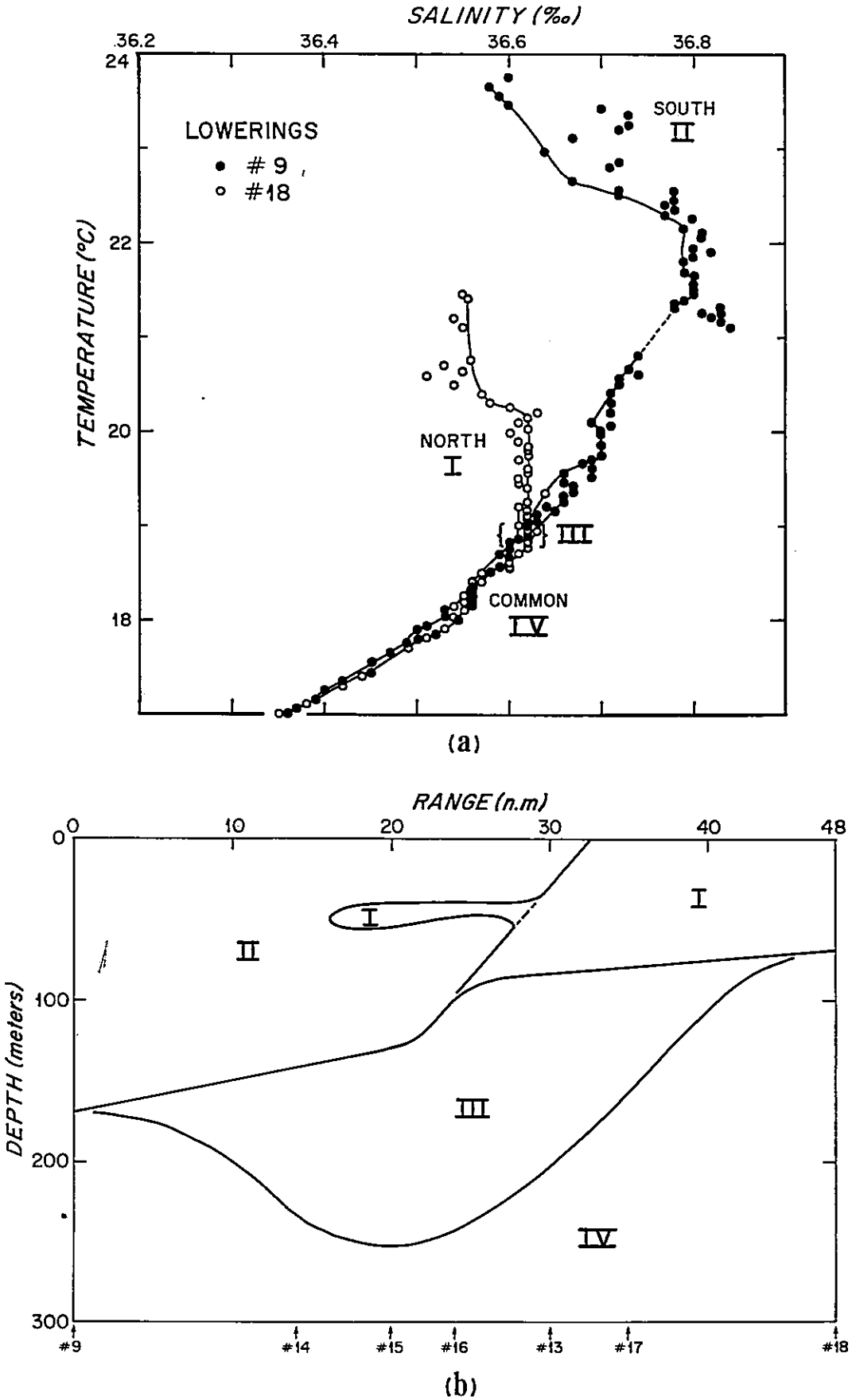

Fig. 1. (Katz) Cross-section of the front by water masses. a. A combined T-S diagram from two lowerings on either side of the front. The branches, branch point and trunk are enumerated. b. Interpretation of the section by water masses as defined by a.

Reference

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A RELATIVELY SIMPLE, BUT RELIABLE, HYDROPHONE CALIBRATION FACILITY

S. T. Knott

In the past year two simple laboratory hydrophone calibration tanks have been set up so that the sensitivity of a wide variety of hydrophones and arrays can be reliably and quickly measured. Calibrations can be made by referring the sensitivity of an unknown to that of a secondary standard transducer over a frequency range from 10 to about 50 Hz. One tank, an 18-inch cylinder with about a 4-inch ID, accommodates a variety of small transducers; the other is a 3-foot diameter roughly spherical tank in which whole arrays of adequate flexibility may be coiled. Calibrations are made under pressure simulating the depths at which the hydrophones are used at sea. The small tank can be pressurized to at least 400 psi, the larger, has been statistically tested to 200 psi. An acoustical signal is generated by varying the internal pressure hydraulically; a simple piston is driven in an oscillating manner. Various means can be used to drive the piston which produces the oscillating pressure field.

The dimensions of the tanks are small in relation to the wavelengths of the range of frequencies being used. Hence one might predict that the phase of the signal would be closely uniform throughout the tanks. This has been demonstrated to be the case by examining the simultaneous outputs of several transducers spaced around the insides of the tanks. No appreciable phase shift is detected.

Although this calibration system has a limited frequency range, the general performance, i.e. resonant peaks, of transducers may be predicted from their physical size and, of course, manufacturers' specifications. These calibrations then, definitely define a group of points at the low frequencies on the response curves of the hydrophones from which their response at higher frequencies may be extrapolated.

This calibration technique is so easily accomplished that in little more than 10 minutes an unknown may be compared to a standard. The pressure range can be extended by simply connecting suitable hydraulic lines to an adequate high pressure tank. The frequency range may also be extended to some extent, but tests here and reports in the literature of similar set-ups suggest that the technique is most likely restricted to the low frequencies up to 100 or 200 Hz (Beranek, 1949); (Golenkov, 1965).

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IMPROVED CONTINUOUS SEISMIC PROFILING RESULTS BY SUMMING THE OUTPUT OF TWO OR MORE HYDROPHONE ARRAYS

S. T. Knott

Almost any improvement in continuous seismic profiling (CSP) technique requires an increase in signal-to-noise ratio. One method that improves the CSP results and appears to hold considerable promise is the summation of the outputs of two or more hydrophone arrays towed together in a spread across the stern of a research vessel. This method of operation was started on *Chain* cruise 70, improved on *Chain* cruise 73 and continued with definite success on *Chain* cruise 75.

When the unfiltered output of a towed array is examined, the seismic reflection signals are found to ride on a noise background that is random in relation to the signal and is several times higher in amplitude especially at the low-frequency end of a band that ranges from less than 10 Hz to several hundred Hz. In addition when the noise received by one array is compared to the noise received simultaneously by another array towed at the same time, the noise of one appears quite random in relation to the other. A number of observations of this sort leads to the conclusion that the noise field associated with one array is peculiar to that array and its towing arrangement. Ship's

propulsion noise, as well, is received with random phase relations at each array location for it is unlikely that there are exactly the same travel times from various noise sources to the arrays. Successive signals are, however, generally coherent and the travel path geometry is such that the reflections received over vertical paths will be received simultaneously, if the arrays are towed at the same depth. Hence, under these conditions, the summation of the coherent signals received on two similarly sensitive arrays causes the signal to be doubled, and the summation of the noise results in the cancellation of much of the noise.

The preliminary results of using this technique suggest the attainment of a greater improvement in the signal-to-noise ratio than might be predicted by simple array theory. The difference, if it is real, may be due to the fact that much of the tow-noise field of one array is peculiar to that array (being self-generated), and the tow-noise most commonly overrides sea-noise or other noise that might be received continuously from the same general source by each of the arrays.

The simple but effective means of summing two outputs that has been employed makes use of the summing circuits in a Tektronix® Oscilloscope CA plug-in or similar units. By feeding the two input channels of this type of plug-in unit and switching to the algebraically added position the summed signals appear on the scope as well as at the vertical amplifier output. Prior to making this selection the input signals may be individually observed on either the separate channel selections or the chopped display. The percentage of each input (usually made equal) may be varied with the input potentiometers, and the signals may be given the same or inverted phase by another switch. Thus the signals may be manipulated as required and the results directly observed on the scope.

Although the observations on the scope are more easily made by low-pass filtering the inputs before being fed to the scope, the graphically recorded results have been essentially the same when filtering is applied either before or after summing. In either case the vertical amplifier output gives the required summed signal and has an appropriate frequency response.

PRELIMINARY ANALYSIS OF SEISMIC REFLECTIONS

S. T. Knott, J. Doutt and P. Kissinger

The characteristics of the acoustical energy reflected from the sea-floor and acoustical discontinuities below the sea-floor should be related to the type of sediments, their porosity, the acoustical impedance of the mass of one sediment compared to another, the roughness of interfaces, the thickness of the layers between interfaces and so forth. Thus, it is logical to ask what additional knowledge might be gained by examining the multitude of reflected signals that have been recorded while obtaining continuous seismic reflection profiles on our many cruises.

The profiles, alone, have given us considerable knowledge of the crustal structures beneath the sea-floor; however, it appears that more information might be extracted towards classifying the sediments by some characteristic of the sound they reflect. Physiographic provinces have been described and reflected energy has been measured. These reflectivity results have been related to the provinces, but the emphasis has been primarily on the energy contained in the frequency region of several kilohertz. Breslau's (1967) work at 12 Khz relates reflectivity to porosity, but the results are based on measurements at only one frequency.

The underwater spark puts out an acoustic pulse having a broad spectrum. It is the systematic examination of data from such a broadband acoustical source that is involved in the present studies.

Several criteria must be known well enough to allow reasonable assumptions to be made in order to derive meaningful results. To date, the source output energy is assumed to be uniformly repeated, and the tow depth to be constant; in addition, the hydrophone depth is assumed constant and equal to the depth of source. Certain studies and measurements indicate that these assumptions are not unreasonable for selected portions of the data. If an array of hydrophones is used, its tow-depth and horizontal attitude must be measured or assumed. A practical means for continuously monitoring the downward radiated energy from the source has not yet been devised, but pressure-time waveforms are inferred from the outputs of blast gauges towed near the source or from similar measurements made at the dock.

Subject to these limitations we can make a number of relative measurements. We can compare the rate that reflected energy is received as a function of frequency and geographic area. The variation in the total energy

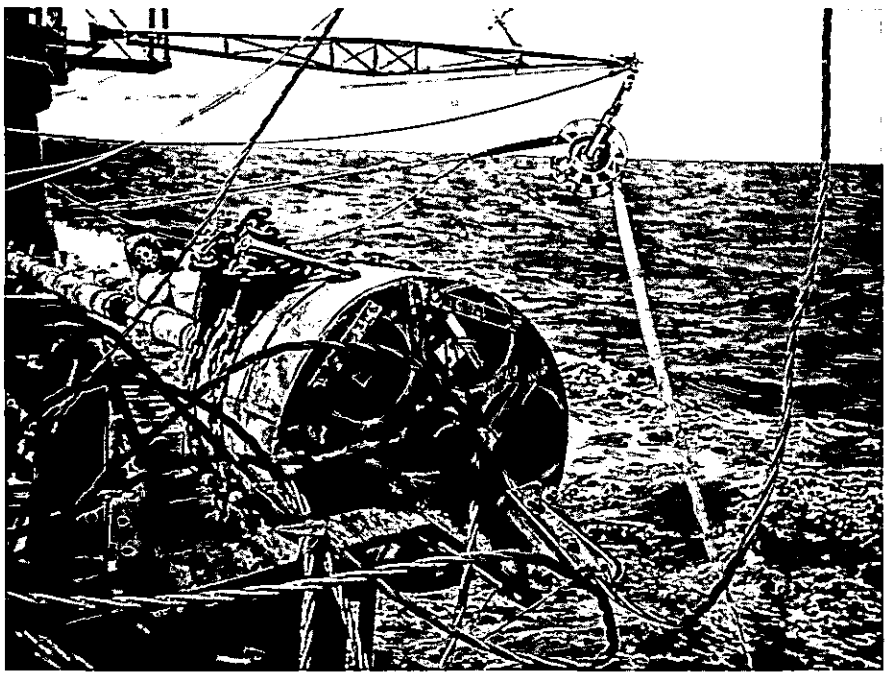

Fig. 1. (McCoy, *et al.)* Two cameras (left and right) and a strobe light source (center) mounted within the core head prior to a coring station. The bracket holding a compass and an inclinometer is shown attached to the upper core barrel.

Fig. 2. (McCoy, *et al.*) Bottom photograph taken on Sta. 7 (1890 fms) by the camera focused at 6 ft. The large sediment cloud is produced during penetration of the corer into the bottom.

Fig. 3. (McCoy, *et al.*) Bottom photograph taken later on Sta. 7 (1890 fms) by the camera focused at 16 ft. The narrow streaming sediment cloud indicates a bottom current to the SSE.

Fig. 4. (McCoy, *et al.*) Bottom photography taken on Sta. 16 (1980 fms) by the camera focused at 6 ft, 5 sec after the piston corer struck the pilot corer during penetration. The detached compass card has been knocked away from the broken compass and is settling to the bottom. Murky water obscures the bottom.

received through a given band pass filter in a given period after the onset of the bottom reflection may be compared with the variations observed at other frequencies. The distribution of these variations is also of interest. Assuming the output of the continuous seismic profiling system to be constant, the reflected energy levels of one area may also be compared with other areas.

A system has been constructed which will compute, simultaneously, the bottom reflected energy in eight different frequency bands and record the results on an eight channel analog recorder and a digital paper tape.

In order to eliminate noise and later sub-bottom arrivals, only the required signal, selected by a gate, is passed through the eight different filters. One group of filters selected from a bank of Logit filters include those with center frequencies of 56.4, 141.0, 446 hertz and 1.41, 3.545, and 5.640 kilohertz.

The values of reflected energy have appreciable scatter. Graphs have been drawn to determine the kind of frequency distribution that the numbers follow. Preliminary results appear to show that the log of the energy (equivalent to the energy in db) may have a normal distribution at the frequencies above 1 Khz. The distribution appears to deviate from a normal one at the lower frequencies.

The buildup of energy at high frequencies is faster than that at low frequencies, and fewer distinct arrivals are apparent. This illustrates the deeper penetration of the sediments by the lower frequencies, and the selective absorption of the higher frequencies by the sediments.

Data from only one area, the Sohm Abyssal Plain (*Chain* cruise 70), have as yet been examined and this has been of preliminary nature. Not all CSP data is suitable; however, a large body of data is available from which to choose.

Reference

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BOTTOM PHOTOGRAPHY WITH A NEW COREHEAD CAMERA

F. W. McCoy, Jr., P. R. Boutin, R. L. Chase, D. M. Owen and R. P. Von Herzen

A new camera-piston coring rig was developed that allows two cameras and a strobe light-source to be mounted within the corehead of a piston corer, in addition to a heat-flow recording instrument and other electronic instruments. The incorporation of cameras in the coring apparatus was designed to take photographs at each coring station in order to (1) record core orientation and inclination, (2) measure bottom currents, (3) study the operation of a piston corer on the bottom, and (4) provide a general knowledge of bottom conditions.

Five cylindrical cavities to hold instruments were built into a 1750 lb corehead (Fig. 1). A compass and inclinometer on a special bracket were attached to an upper core barrel made of non-magnetic stainless steel. The cameras were focused at 16 ft and 6 ft to give bottom photographs at both high and low penetrations of the corer into the bottom; the 6 ft focus was also focused on the compass and inclinometer. To provide a sequence of bottom photos showing the progressive change in shape of the sediment cloud produced when the corer enters the bottom, the flash interval of the strobe light was set to give an exposure every 5 seconds. By this means a measure of the magnitude of bottom currents is obtained. Such a sequence also yields information on the coring process. A timer set on deck before each lowering triggered the cameras and light source just prior to the tripping of the piston corer.

The new coring rig was successfully used on *Chain* cruise 75, where photographs were obtained on 34 out of 35 coring stations. These photographs are presently being studied; a selection of them from coring stations 7 and 16 are shown in Figs. 2-4. Figure 2 was taken with the camera focused at 6 ft during penetration of the core into the bottom on Sta. 7, showing a large sediment cloud dispersing around the barrel. Figure 3, taken a few minutes later with the camera focused at 16 ft shows the core at maximum penetration with a bottom current trending SSE. During station 16, the compass-inclinometer bracket arm on the upper barrel of the piston core struck the weights of the pilot corer after being tripped, breaking the compass; Fig. 4 was taken with the camera focused at 6 ft, 5 seconds after the impact and shows the compass already broken, and the detached compass card knocked away and sinking to the bottom.

GENERALIZED WKB-METHODS APPLIED TO DIFFRACTION EFFECTS IN SOUND PROPAGATION

E. L. Murphy

An analytical study, begun in 1966, of diffraction phenomena associated with so-called turning-point regions (where a ray reverses direction) in a medium with spatially varying sound velocity was described in the 1966 Summary of Investigations. In particular, a mathematical technique called the "generalized WKB-method" was used to obtain a mathematical expression (contour integral) representing the reflection or transmission of a collimated plane wave incident on a region having a local maximum in the sound velocity profile. In this way, in analogy with quantum mechanical barrier penetration, one can describe the transmission from a beam that on the basis of ray theory would be totally reflected, or the reflection from a beam that on the basis of ray theory would be totally transmitted.

Under certain conditions the contour integral, representing the collimated beam, can be approximated using the so-called saddle-point approximation; at least part of the contribution to the transmission or reflection can be described in this way.

An analysis has been completed, following this procedure, for some of the diffraction effects that arise in a velocity profile for which there is a split-beam shadow (that is, for a velocity profile for which there is a "critical ray" that splits at the level of a velocity maximum and such that no geometrical-optics rays extend beyond this limiting ray). A ray-like representation for some of these diffraction effects, the nature of the penetration of diffracted energy into the geometrical shadow, the wavelength dependence of these contributions, and the limits of applicability of this technique have been obtained.

There exist ranges of the parameters for which contributions to the integral for the collimated beam, in addition to the saddle-point contribution, may be significant. In fact, there may be contributions to the reflection or transmission of a spherical wave from a continuously varying medium having a local velocity maximum, perhaps, somewhat like the lateral wave contribution to the reflection of a spherical wave from the interface between two homogeneous media. To explore this possibility the analysis described above has been extended to the reflection and transmission of spherical waves and the resulting contour integrals are now being studied.

GEOMAGNETIC STUDIES OVER THE OCEAN

J. D. Phillips

Geomagnetic studies during the last year have included both shipboard and airborne magnetic profiling over the ocean. Our investigations were concerned primarily with the anomalous magnetic field over the Mid-Atlantic Ridge and the sea-floor spreading hypothesis. A study over the ridge near 27°N (*Chain* 61) showed magnetic trends that are parallel to the ridge axis and symmetrical about the ridge axis (Phillips, 1967). The configuration of magnetic bodies that could account for the pattern supports the Vine and Matthews (1963) hypothesis for the origin of magnetic anomalies over oceanic ridges and sea-floor spreading. A polarity reversal time scale inferred from radiometrically dated reversals of the geomagnetic field indicates a spreading rate of 1.25 centimeters per year during the last six million years and a rate of 1.65 centimeters per year between 6 and 10 million years ago (Fig. 1).

We have made a similar analysis of more limited data over the ridge near 22°N (*Chain* 44). A change in the spreading rate is also indicated here. A rate of 1.4 centimeters per year appears to have been in effect during the last five million years; between five and nine million years ago, an increased rate of 1.7 centimeters is indicated.

Further confirmation of the Vine and Matthew hypothesis and sea-floor spreading was afforded by a study over the Mid-Atlantic Ridge between 45° and 43°N (*Atlantis II*-32). However, a large portion of the surveyed area is not easily explainable in terms of sea-floor spreading. Of five magnetic and bathymetric profiles, 450-180 km long, and spaced 20-40 km, symmetrical north-south magnetic trends parallel to the ridge axis are recognizable only over the two southernmost profiles. Here the ridge is characterized by a well-developed central rift valley. The three northernmost profiles do not contain obvious magnetic symmetry elements and are over a portion of the ridge characterized by rugged topography without a central rift. On the bases of these long, widely spaced profiles a smaller detailed study was made across the ridge between 42°30′N and 43°30′N in order to span the region of apparent change in its character. Here a narrow zone transverse to the ridge axis showed abrupt termination of the symmetrical

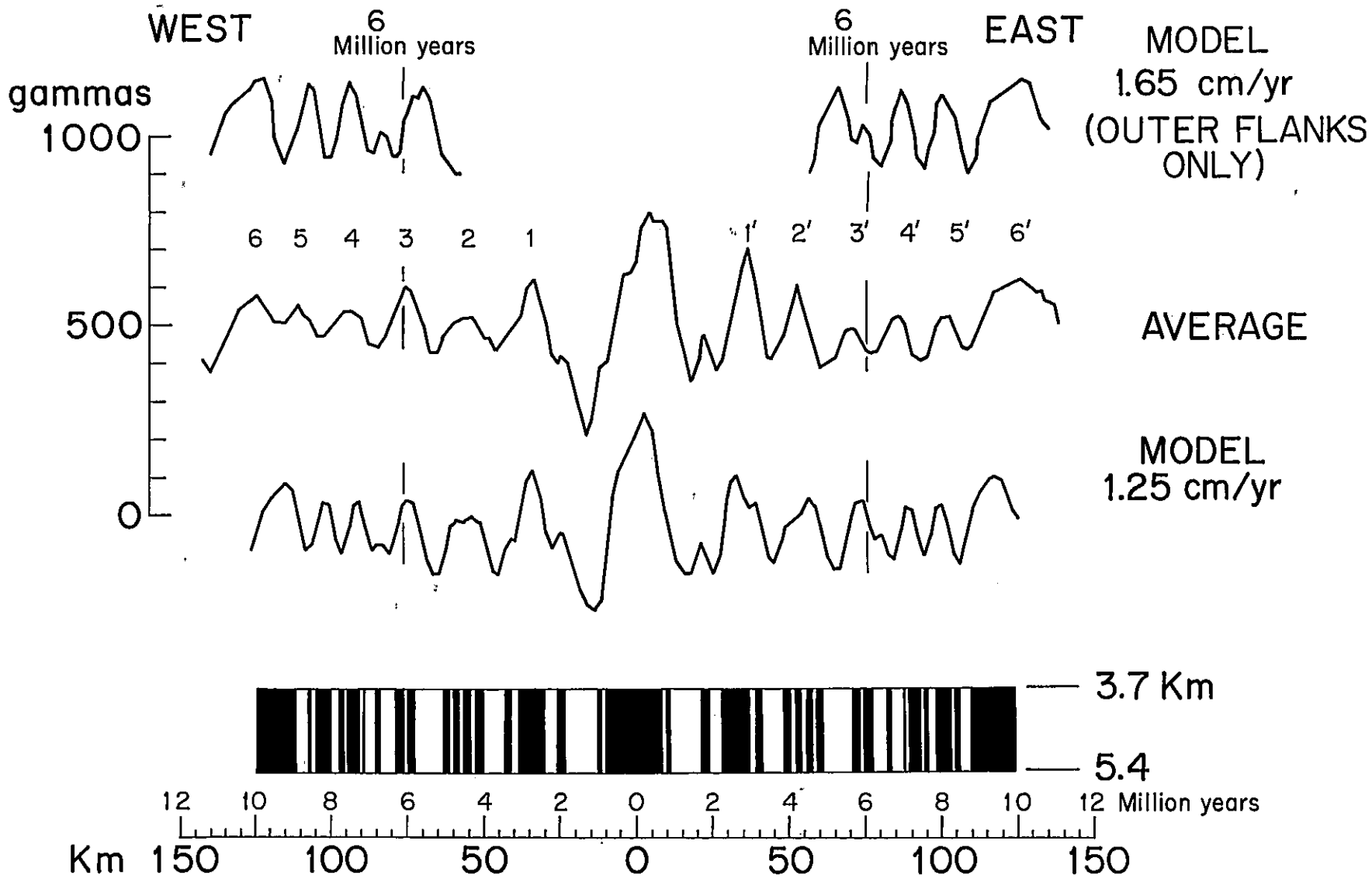

Fig. 1. (Phillips) At the bottom is the seafloor spreading model for the Mid-Atlantic Ridge at 27°N. The upper surface of the magnetic layer is at the approximate sea-floor depth. The configuration of normally and reversally magnetized blocks in the layer was determined from the Pitman and Heirtzler polarity reversal time scale. The time scale (millions of years ago) is related to the distance scale by a 1.25 cm/yr spreading rate. The lower curve is the simulated anomaly profile computed from the magnetic layer. Total intensity of rock magnetization is taken to be 0.0025 centimeter-gram-second units except central block which is 0.005. Inclination of magnetization is 46°. The ridge axis strike 22°E. Middle curve is the observed average profile across the ridge. Top curve shows the outer flanks of a simulated profile for a spreading rate of 1.65 cm/yr compared to the observed average profile.

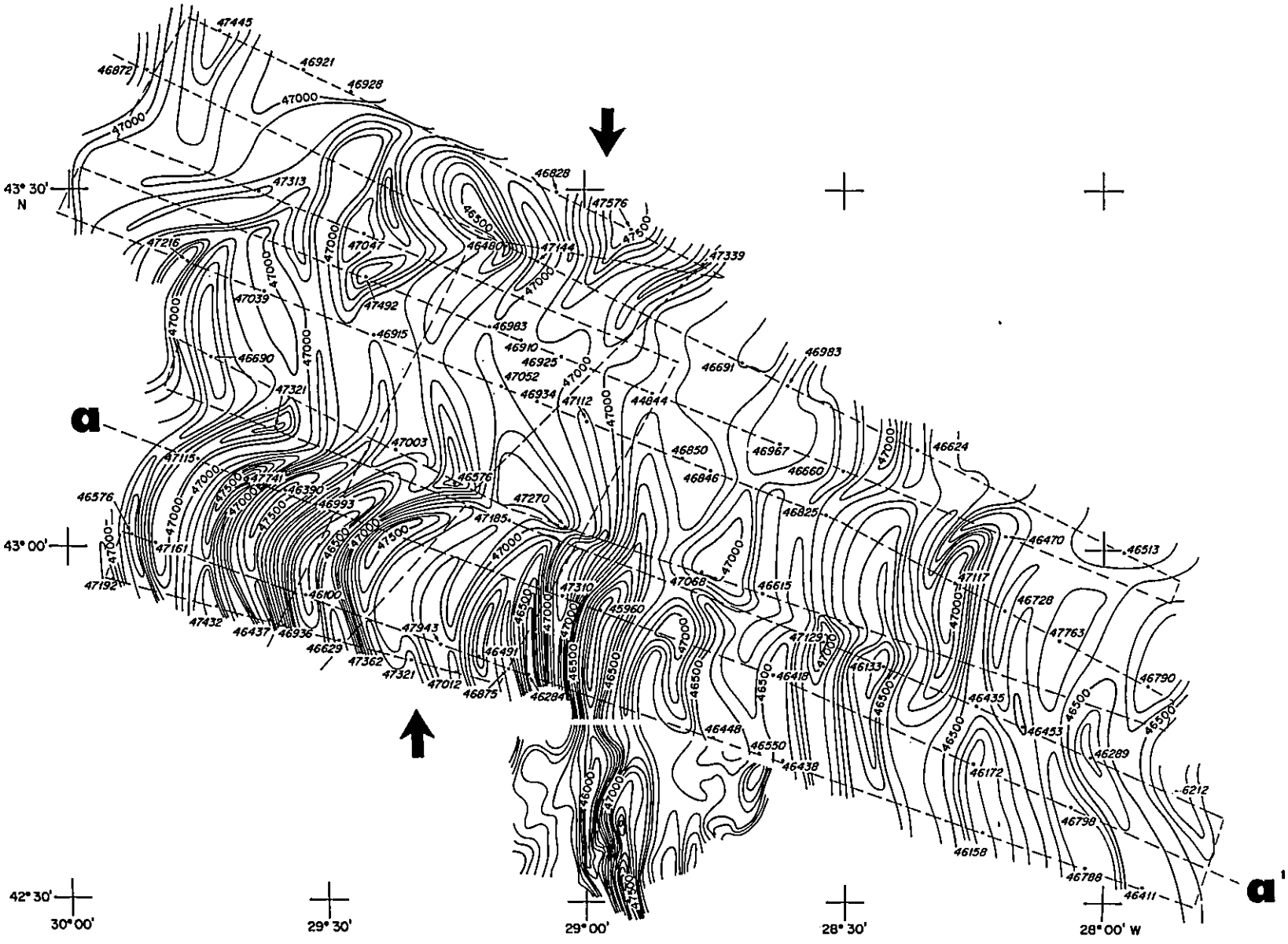

Fig. 2. (Phillips) Total magnetic intensity contour chart of the *Atlantis II* and *Chain* 43 survey area over the Mid-Atlantic Ridge. The contour interval is 100 gammas. The line a-a' is the track of the AII-32C profile across the survey area. The bold vertical arrows mark the position of the central rift valley.

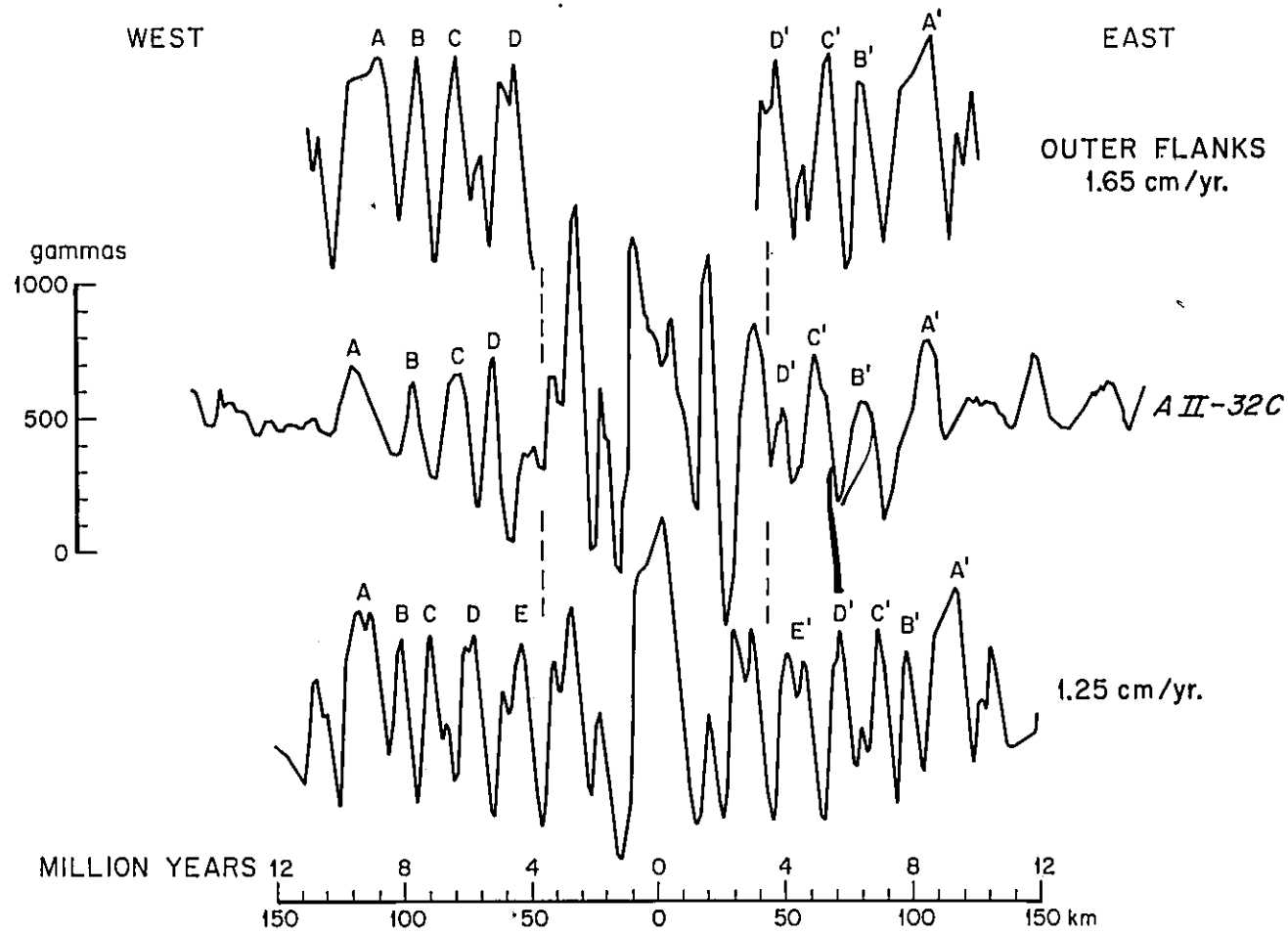

Fig. 3. (Phillips) At the bottom is a simulated profile generated from a seafloor spreading model for the Mid-Atlantic Ridge at 43°N. The upper surface of the magnetic layer is taken at the approximated sea-floor depth of 2.9 km. The layer is 1.75 km thick. The configuration of normally and reversally magnetized blocks in the layer was determined from the Vine geomagnetic polarity reversal time scale. The time scale (millions of years ago) is related to the distance scale by a 1.25 cm/yr spreading rate. Total intensity of rock magnetization is 0.0047 centimeter-gram-second units, except for the central block which is 0.0094. The inclination of the magnetization is 64°. The ridge axis strikes 19°E. The primed and unprimed letters A-D refer to symmetrical anomaly pairs believed to be represented in the observed profile *Atlantis II*-32 C shown in the middle curve. Anomaly pair E of the simulated profiles, which is shown only in the 1.25 cm/yr profile to preserve the figure's clarity, is not believed represented in profile *Atlantis II*-32 C. The top curve shows the outer flanks of a simulated profile for a spreading rate of 1.65 cm/yr. It has been oriented so that the 6 million years ago position of the simulated profile is approximately aligned with the 4 million year-ago position of the 1.25 cm/yr simulated profile. The vertical dashed lines enclose the central region anomalies which are easily compared to the 1.25 cm/yr simulated profile. The close correspondence of the profiles is best seen by holding the page nearly horizontal at eye level.

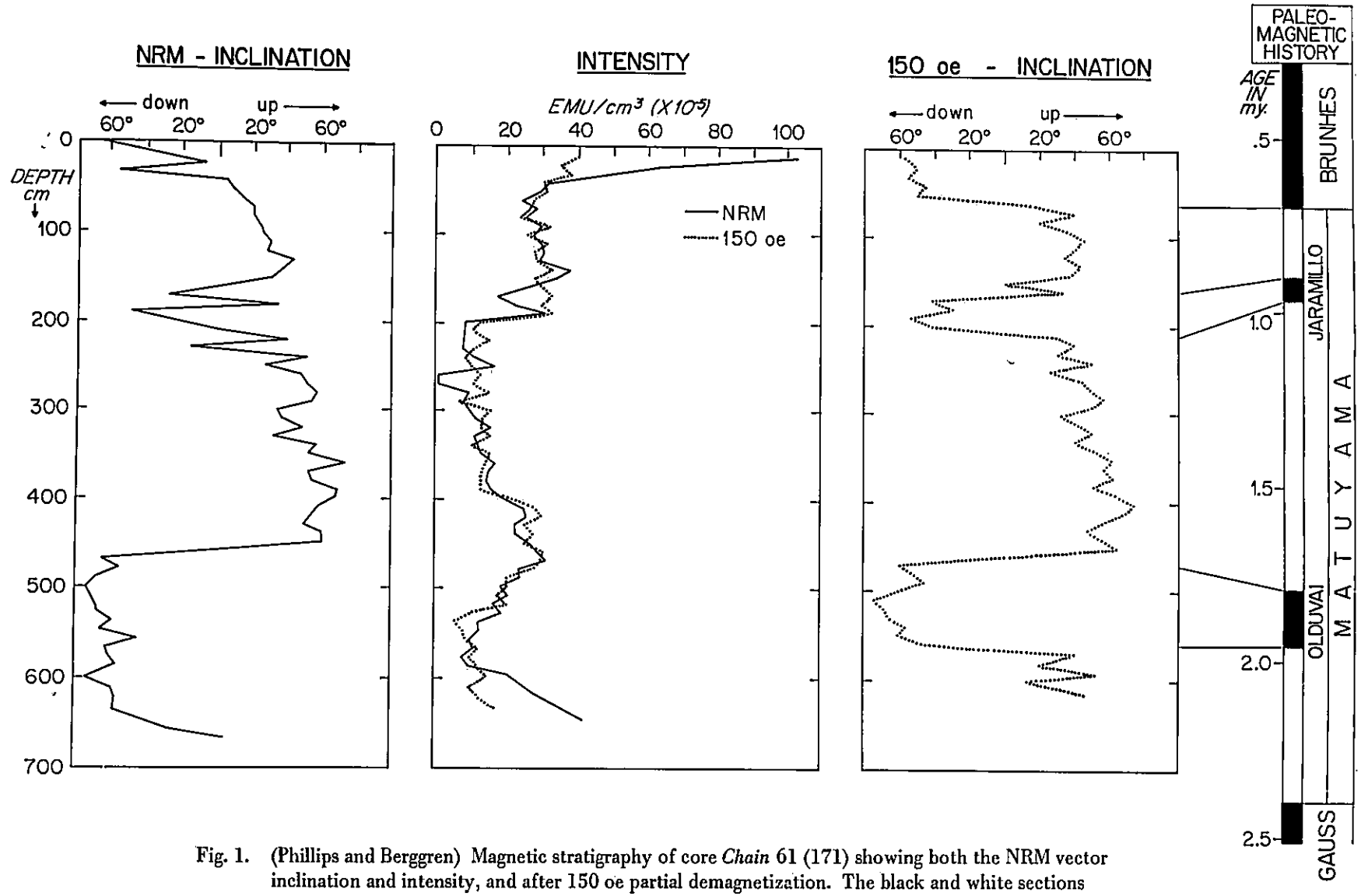

Fig. 1. (Phillips and Berggren) Magnetic stratigraphy of core *Chain* 61 (171) showing both the NRM vector inclination and intensity, and after 150 oe partial demagnetization. The black and white sections at the extreme right indicate normal and reversed polarity intervals, respectively of Pitman and Heirtzler's geomagnetic polarity time scale.

north-south magnetic trends and central rift valley each well developed in the southern part of the survey area (Fig. 2). North of this zone there is little evidence of a symmetrical magnetic pattern or central rift valley.

Dredge rocks and heat flow measurements in the respective area also showed striking differences. Basalts and relatively low heat flow (0.6 μcal/cm^2 sec) characterized the southern area, even in the central rift valley, whereas serpentinized peridotites and very high heat flow (3-7 μcal/cm^2 sec) were observed in the northern area.

Model studies suggest that the configuration of magnetic bodies that could account for the symmetrical magnetic pattern of the southern area generally supports the sea-floor spreading hypothesis. A spreading rate of about 1.25 cm per year active of the last 5-6 million years is indicated (Fig. 3). Beyond about 6 million years ago the magnetic profile, while still symmetric about the ridge axis, is difficult to interpret in terms of a continuous sea-floor spreading model. It appears most likely that spreading had effectively stopped between 5 and 6 million years ago. This is inferred from the absence of anomaly pair DD' in the observed profile AII-32C of Fig. 3. However, a spreading rate of about 1.65 centimeters per year appears to have been active between 6 and 11 million years ago since the simulated profile at the top of Fig. 3 matches closely the outer flanks of the observed profile AII-32C.

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PALEOMAGNETIC STUDIES OF DEEP-SEA CORES

J. D. Phillips and W. A. Berggren

Recent paleomagnetic studies of deep sea cores have shown that geomagnetic polarity-reversal history is recorded in the remanent magnetization of sea-floor sediments (Opdyke *et al.*, 1966). Our investigations have been directed toward relating the inferred "absolute" time scale afforded by the magnetic polarity sequence along a core's length to the geologic time scale and major climatic changes indicated by the microfossil content of the cores (Berggren, *et al.*, 1967).

For example, Fig. 1 shows the inclination and intensity of the remanent magnetization along a core from the central-north Atlantic Ocean (Phillips, *et al.*, 1967) both before and after an alternating magnetic field treatment which removes spurious magnetic effects. This polarity sequence has been related to the known geomagnetic time-scale to the right of Fig. 1 by assuming that a reasonably constant sedimentation rate prevailed and that each successive polarity interval of the core represents each known geomagnetic polarity epoch. In this way the "absolute" date of the core sediments can be determined.

Micropaleontologic studies were also made of this core. A microfossil boundary, specifically the *Globorotalia tosaensis - Globorotalia truncatulinoides* phylogentic transition, was found at a depth of 500 cm (Fig. 2). This boundary can be used to define the Pliocene/Pleistocene geologic boundary. This transition appears to have occurred during the upper portion of the Olduvai Normal Magnetic Event (Fig. 2). An age of 1.8 million year for the Pliocene/Pleistocene boundary can be inferred on the basis of the paleomagnetic stratigraphy of the core.

A similar paleomagnetic technique has been applied to other cores from the North Atlantic Ocean and Mediterranean Sea to date major climatic change during Pleistocene time. Paleontologic studies have shown that a change in the relative abundance of certain deep sea microfossil faunas can be used to infer change in the oceanic water temperature. One such abundance ratio change was clearly marked in the three cores shown in Fig. 3, namely the marked increase in abundance of *Globorotalia inflata* and *Globorotalia hirsuta* (cool-water species) and a corresponding decrease of *Globerginoides ruber* and *Globerginoides sacculifer* (warm-water species). In each of the cores this transition is noted within the Jaramillo Nomal Magnetic Event at about 0.9 million years ago. This faunal change probably corresponds to a major cooling trend and may reflect the initiation of Pleistocene glaciations of Europe and North America.

Fig. 2. (Phillips and Berggren) Origin and evolution of *Globorotalia truncatulinoides* in core 171. In the lower, disturbed part of this core *G. tosaensis* is commonly present and shows gradations to *G. crassaformis* from which it evolved. This suggests that the lower part of Zone N21 may lie within the lower (disturbed) section of this core or a short distance below the level of 722 cm penetrated by the core. In the interval between 585 cm and 400 cm the transition to and development of *G. truncatulinoides* can be followed. The primary characters which distinguish *G. truncatulinoides* from *G. tosaensis* include: (a) development of a larger, more robust, smoother walled test, (b) development of a marginal imperforate carina (keel) along the peripheral margin of the test, (c) development of a higher more acutely angular periphery (seen best in edge view). The apertural face of the final chamber is commonly depressed into a sulcus in *G. truncatulinoides*, (d) development of more evolute coiling with the result that the umbilicus is more widely open and bordered by steep, smooth walls along the umbilical margin. The development of a thickened umbilical collar around the umbilical shoulder is also seen in some specimens of *G. truncatulinoides*. These two features lead to forms which are strongly reminiscent of some forms assigned to *Globorotalia caucasica* - a species common in the upper Early Eocene in some areas, (e) development in morphologically more advanced forms of an overlapping (imbricating) chamber arrangement quite distinct in this species. In core CH 61 (171) the transition from *G. tosaensis* to *G. truncatulinoides* can be seen to begin at 540 cm. The development of a more angular test and the beginning of an incipient keel (on the last formed chamber) can be seen at 530 cm. The peripheral margin on *some* specimens is strongly thickened presaging the gradual development of a marginal keel. If the concept of *G. truncatulinoides* is based primarily on the first appearance of an imperforate keel, the first specimens of this species could be said to occur at 530 cm. However, the concept of *G. truncatulinoides* used here is based upon a totality of characters (summarized above) which serve to distinguish it clearly from *G. tosaensis*. Thus the peripheral keel appears to be fully developed and fixed as a genetic character within the assemblage examined first at 500-502 cm. Specimens at this level still exhibit the tight coiling and generally narrow umbilicus typical of *G. tosaensis*; however, forms referable to *G. tosaensis* continue to accompany *G. truncatulinoides* but become rarer in proportion to the rapid expansion of *G. truncatulinoides* in samples above 480 cm.

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Phillips, J. D., W. A. Berggren, A. Bertels and D. Wall (submitted for publication) . Paleomagnetic stratigraphy and micropaleontology of three deep-sea cores from the Central North America.

NATURAL SOUNDS OF THE SEA

William E. Schevill and William A. Watkins

Among the investigations that have occupied us this year are several dealing with pinnipeds in high latitudes.

Among our Antarctic data are records of an experiment in which we played back the sounds of Weddell seals (*Leptonychotes weddelli)* to seals of the same species under the ice of McMurdo sound, and obtained positive responses. The seals responded vocally to good fidelity playback as if another seal were present. We recognized three broad categorical meanings derived from the hours of working with these seals: (a) trills, probably dominance, (b) low pulses, evidently threats, and (c) chirps, possibly inquiry. The latter may also have had some navigational value, since they were the sounds consistently, though intermittently, used while swimming between holes.

A comparison was made of the sounds of Arctic bearded seals (*Erignathus barbatus)* with those of the Antarctic Weddell seals (*Leptonychotes weddelli).* Both seals were recorded during the early spring season. The bearded seal produces a long (up to a miniute or more) frequency-modulated song that is characterized by rapid sinusoidal excursions in frequency. The song has an overall dropping frequency characteristic. The Weddell seal

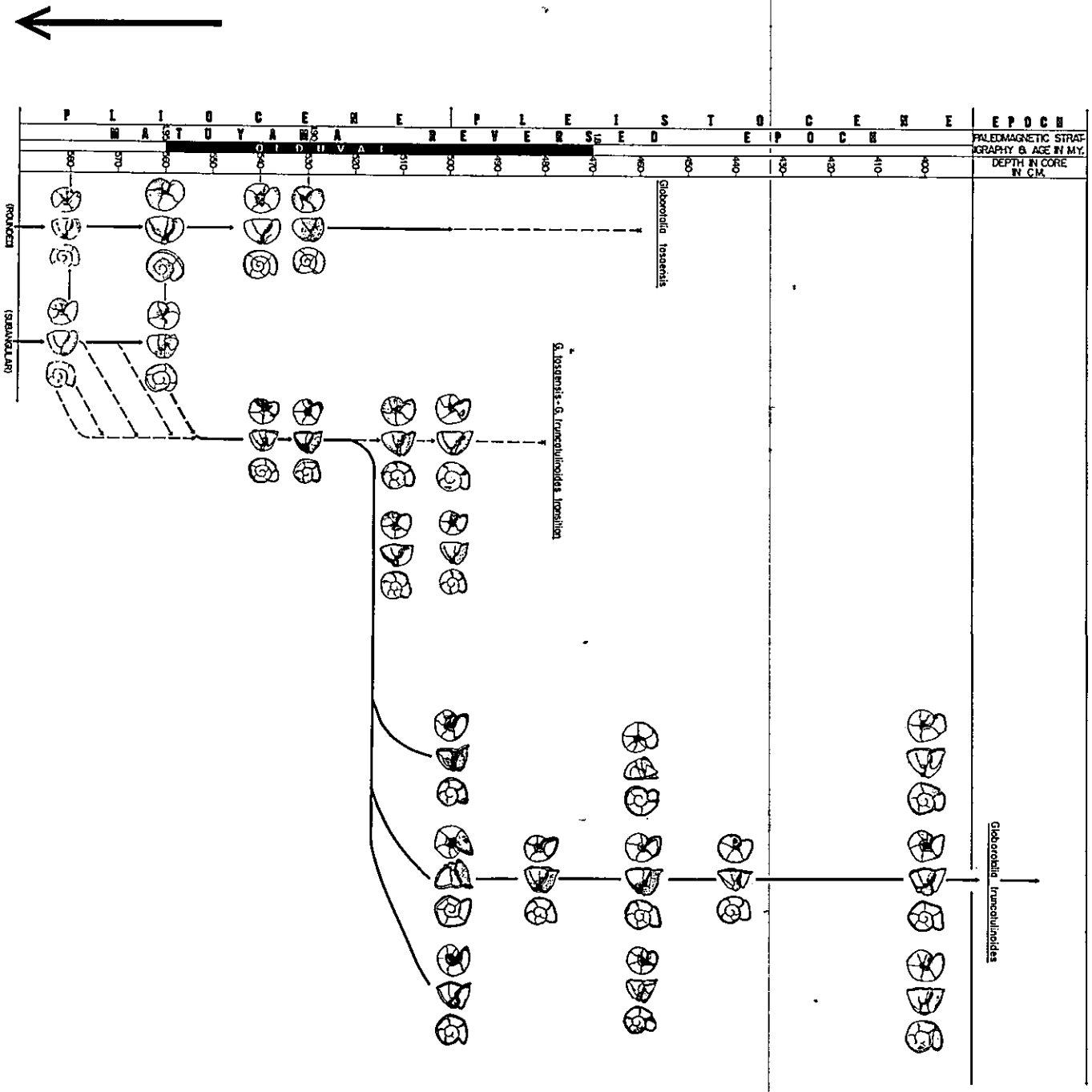

Fig. 2. (Phillips and Berggren)

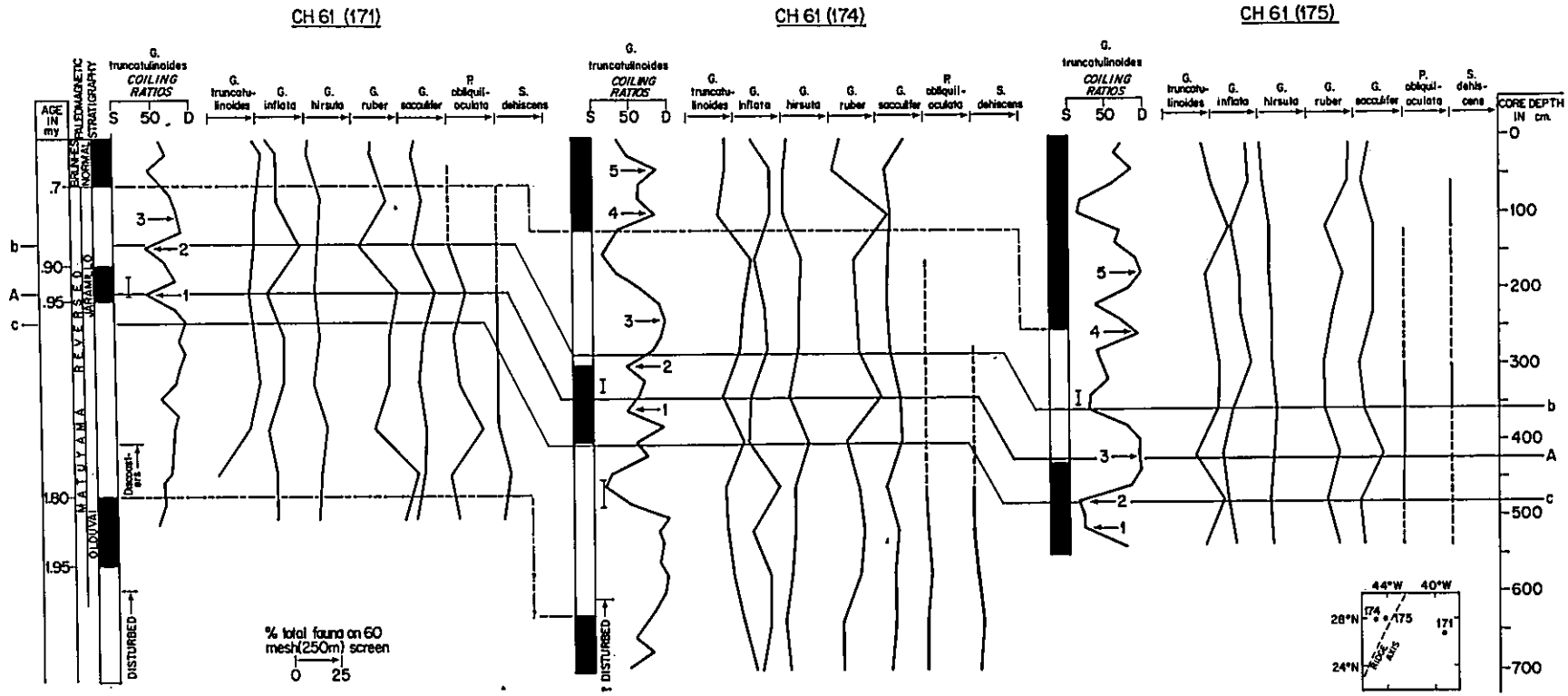

Fig. 3. (Phillips and Berggren) Comparison of the paleomagnetic and micropaleontologic stratigraphy of cores *Chain* 61 (171), (174) and (175). The horizontal lines show suggested levels of correlation among the cores based on distinctive fluctuations in the coiling ratio abundance of *G. truncatulinoides* and the relative abundance of the indicated foraminiferal species. The numbers are believed to mark points of general correlation in the coiling ratio curves for each core. The vertical bars adjacent to the magnetic stratigraphy column for each core delineate narrow bands of light grey-brown foraminiferal lutite in the otherwise homogeneous pale brown foraminiferal lutite. The sketch shows the location of the cores.

also may produce a long trilling call (40 seconds or more) of dropping frequency; the Weddell trill, however, is composed of discrete pulses rather than being frequency modulated. Both these animals contribute heavily to the underwater ambient sound in their respective regions.

The three-hydrophone array we employed under the ice in the 1964 Antarctic work with Weddell seals produced good information on seal tracks as they approached the breathing hole. Swimming depths of 50-100 meters were the most common. There was relatively little swimming up close to the ice. Effects of pressure on the sound of the seals appears to be negligible at these depths. There was nearly no reflection of sound from the under-surface of the ice. A directional pattern in the sound transmission of the seals is suspected, and may contribute to the sound transmission anomalies noted. Sound-ray propagation to hydrophones at varying depth was compared. Shallow hydrophones had relatively long range listening capabilities and hydrophones on the bottom had short ranges at these 300 m depths; this was due to the low level of reflection from the ice cover and a consistent upward sound refraction pattern.

To compare the underwater sounds of the Antarctic pack ice with that from ice newly formed in higher temperatures, we accepted an invitation from the Fisheries Research Board of Canada to visit the Gulf of St. Lawrence in early March just before the opening of the annual harp seal hunt. Most of our work was done near the Magdalen Islands. The ice was only a month or so old, and was quite soft and not very thick (a meter or less). The ice pans varied from a few meters to about 1000 meters or more across, and had a 10 to 20-cm snow cover. The ice-contributed sounds were of two sorts: (1) A high-frequency hissing background reminiscent of the higher components of electrical thermal noise; these may have resulted partly from the presence of snow chunks continually falling into the water and the collapse of associated air bubbles. (2) A crackling lower-frequency hiss heard in waves of several seconds up to several minutes in duration was caused by the movement of one floe rubbing past another. The ice field was continually in motion. *Phoca groenlandica*, the harp seal, was gathered in herds in this same area at the beginning of the pupping season. Underwater sounds recorded from these seals have all the variety and noisy flavor of a busy barn yard. In the air no sound was heard.

OCEAN-FLOOR GEOTHERMAL STUDIES

R. P. Von Herzen, A. E. Maxwell and R. J. Hessler

This year's progress centered around measurements of heat flow at sea, for the most part on and adjacent to the Mid-Atlantic Ridge. The goal of these investigations is to determine any systematic variation of the heat-flow pattern over the ridge, and to determine the causes of the large variability over the ridges, as a clue to the tectonics of the sea floor. Most of the measurements were made with relatively standard instrumentation used with piston coring techniques or with a 2-meter probe; the combination of both techniques increases the number of successful stations at sea and allows access to a wider range of sea-floor environments. Some new innovations in instrumentation were used successfully near the end of the year, as described below.

After some instrumentation tests on *Chain*-63 cruise, about 75 measurements were made at sea on cruises *Atlantis II*-31 (April-May), *Atlantis II*-32 (June-July), and *Chain*-75 (Nov.-Dec.) in cooperation with the Massachusetts Institute of Technology. The measurements on the *Atlantis II* cruises were carried out in conjunction with other geological-geochemical programs, and the *Chain*-75 cruise involved extensive geological-geophysical investigations. The *Atlantis II*-31 cruise measurements were distributed over an area of the ridge crest near 11°N, which includes a major transverse displacement of the ridge crest by the Vema Fracture Zone. The *Chain*-75 cruise established two profiles of measurements from the Lesser Antilles to the Mid-Atlantic Ridge, immediately to the north of the Vema fracture (12-44°N). A long profile of measurements from England to Canada, crossing the ridge at 43°N, was made on *Atlantis II*-32 cruise.

The large variability in heat-flow values measured near the ridge crest on all three cruises conforms with those of other studies elsewhere. Many of the lowest values indicate a condition of thermal disequilibrium on the sea floor, and we intend to investigate this in more detail in the future. A possible zone of low values on the lower ridge flanks, indicated by other previous measurements, was not systematically observed on the long profiles. Bands of sediment with unusually high (twice normal) thermal conductivity were found in cores on the western flank of the ridge and adjacent Newfoundland basin on the *Atlantis II*-32 cruise.

A relatively short probe (2 m) with a short thermal time constant (few minutes) was developed for detailed work. Unfortunately, this instrument was lost on its first test, and additional instruments are being constructed. A new piston coring head was developed for *Chain*-75 cruise, permitting cameras and other electronic instruments to be mounted on the coring rig in addition to heat-flow apparatus. A telemetering pinger was used successfully with this corer on *Chain*-75 cruise to transmit and record aboard ship in real time the heat-flow information and a magnetic orientation of the corer.

R. P. Von Herzen participated in a panel concerned with geothermal measurements on the JOIDES deep-sea drilling program, which is scheduled to begin an 18-month period of field operations in mid-1968. This program should establish very reliable oceanic heat-flow measurements, on which future detailed studies may be based.

DINOFLAGELLATE STUDIES

David Wall and Barrie Dale

Dinoflagellate life histories are being studied with special emphasis on the encysted stage of meroplanktonic species. Cysts of numerous species are being investigated biologically and paleontologically to determine their roles and potential applications to the systematics, ecology, paleoecology and stratigraphy of dinoflagellates.

The year 1967 has been devoted to the completion of several investigations. A monographic treatise was prepared to deal with the morphology and paleontological significance of dinoflagellate cysts which has been our major concern for several years. In this work the resting cysts (spores) of over thirty species of modern marine and freshwater dinoflagellates belonging to the genera *Gonyaulax, Protoceratium, Peridinium, Diplopsalis, Diplopsalopsis, Diplopeltopsis* and *Scrippsiella* were described and their systematic relationships with fossil dinoflagellates and hystrichospheres were discussed. These modern cysts were studied at Woods Hole from local waters in association with natural populations and in a series of over seven hundred incubation experiments: fossil or subfossil cysts also were examined from Caribbean, Mediterranean and Western Arabian Sea surface sediments. It was concluded that: (1) resting cysts of modern thecate dinoflagellates are homologous with fossil dinoflagellates and hystrichospheres with archeopyles and acid-resistant cell walls, (2) that systematic morphological fluctuation shown by the cysts of modern Peridiniales essentially follows the pattern already established from their thecal morphology and that (3) this conformity in present day theca-cyst relationships reflects the evolutionary development of the Peridiniales as it can be traced in geological history. Finally, it was recommended that all the Peridiniales be classified according to a single standard with a single nomenclature and that the present system whereby fossils and living forms are classified separately be abandoned.

Some unique calcareous resting cysts were singled out for special consideration in a separate study. Here it was pointed out that *Calciodinellum operosum* Defl. 1947, the type genus of the family Calciodinellidae and eight new types of calcareous dinoflagellates have been discovered in marine Quaternary sediments from the North Atlantic, Mediterranean Sea, Caribbean Sea and Indian Ocean. Six of these types were studied *in vitro* in incubation experiments after isolation from surface sediments. Two types were germinated successfully and identified as cysts of *Peridinium trochoideum* (Stein) Lemm. and *Scrippsiella sweenyii* Balech ex Loeblich III while four other types produced athecate, hypnoid protoplasts of a type often seen in cultures of the former two species. It was concluded that Quaternary calcareous dinoflagellates are peridiniacean resting cysts with apical archeopyles that are produced by a small monophyletic group of dinoflagellates with the unique ability to effect primary mineralization. We suggested that previously described Mesozoic and Tertiary calciodinellids are homologous and have the same basic affinities in all probability, although they need re-investigation now.

A freshwater dinoflagellate, *Peridinium limbatum* (Stokes) Lemmermann, was given special attention in a study conducted jointly with Professor W. R. Evitt of Stanford University. In a paper devoted to this species, thecae, cysts within thecae and various stages in the cyst formation were described for specimens taken from Round Pond in Falmouth. They were compared with *P. limbatum minnesotense* recently described from Weber Lake, Minnesota by Eisenack and Fries (1965) and it was concluded that the latter "subspecies" really is a cyst of typical *P. limbatum*. The cyst of *P. limbatum* has two cell walls which are precisely comparable with those found in fossil dinoflagellates such as *Deflandrea phosphoritica* Eis. so that the inner cyst wall of *P. limbatum* is homologous with the "capsule" of

typical fossil dinoflagellates. Capsule formation in *P. limbatum* occurs early during encystment and the capsule is a primary structure. The archeopyle or excystment aperture is a lateral, longitudinal suture in the epitract of the outer wall and capsule and is a new type. Scanning electron microscope photographs were used to illustrate this paper.

A stratigraphic study of the Lower Pleistocene dinoflagellates of the Royal Society Borehole at Ludham in East Anglia was completed. A revised and more complete account was given of 'hystrichospheres' first encountered by Dr. Richard West who collaborated in this study and described informally by him in 1961. These organisms were identified formally in paleontological terminology and were typical gonyaulacacean and protoceratiacean fossilized resting cysts. Five species-associations were distinguished in a vertical sequence and the distribution correlated with the local paleontological horizons previously erected from studies of pollen grains and Foraminifera. The palaeoecological significance of this observed distribution was discussed with reference to palaeoclimatic change and the future use of dinoflagellates in local problems involving Quaternary stratigraphy.

Finally a synoptic review was prepared for inclusion in the Proceedings of the Cambridge Symposium on the Micropalaeontology of Marine Bottom Sediments.

A study of the distribution of dinoflagellates in piston cores from the Red Sea was commenced in cooperation with Dr. John Warren who was a summer Visiting Investigator. In another project, discoasters were studied in relationship to other micropaleontological criteria and palaeomagnetism as these were relevant to the age of the Pliocene-Pleistocene boundary in an investigation instigated by Drs. J. Phillips and W. Berggren.

A large number of samples were collected in the early part of 1967 in *Gosnold* Cruises 96 and 97 which visited Lake Maracaibo, the Cariaco Trench and the continental shelf south of Jamaica. These samples are primarily for future biogeographic studies we plan for 1968. Mr. Dale made two dives with *Alvin* and collected surface bottom samples from the continental slope near Oceanographers Canyon. During these dives a chance encounter with an abandoned Grumman Wildcat fighter aircraft created an unusual situation.

MULTIPLE SPARK ELECTRODE SOUND SOURCES

W. E. Witzell and S. T. Knott

For many years an underwater spark discharge of electrical energy has been used to generate reproducible acoustic pulses whose spectra are composed of a broadband of frequencies. These acoustical pulses are explosive in nature and are used as a sound source for continuous seismic reflection profiling and sound transmission studies.

Seismic reflection profiling presents an awkward signal-to-noise problem in that the frequency content of signals is commonly similar to that of the background noise. Source levels are therefore important. The common method of discharging the energy stored by capacitors in an arc from a single electrode into the sea-water electrolyte is well-known, and is noted not only for its inefficiency, but also for its flexibility in application. The output waveform is characterized by a discharge pulse of relatively short rise time and nearly exponential decay that is followed by a sharp bubble pulse (or pulses) of rapid rise time and relatively short duration caused by the collapse (and possible subsequent oscillation) of the transient cavity made by the spark.

In an early use of the continuous seismic profiler (CSP) at sea the spark was discharged from a stored-energy level of 400 joules via a single electrode into the sea water (Hersey and Knott, 1962). It produced useful results, but even better results were desired to probe the deeper structure of the continental shelf (Knott and Hoskins, in press). To improve the output of the 400 joule system, multiple spark-electrode arrays were devised that produced higher-level acoustical signals than were previously attained from the same source of stored energy (Knott and Witzell, 1966). The peak pressure of the discharge pulse of the 400 joule spark was increased more than an order of magnitude, 26 db, and it was found that the period between the discharge pulse and the bubble pulse could be reliably varied to control the resolution of the CSP system. In addition, by virtue of the multiple simultaneous sources they could be arranged to give directional source characteristics at chosen frequencies.

Larger underwater spark sources were developed, such as the 100 K joule system presently on the *Chain*, to increase output signal level. Even with these sources, higher output levels are required, and hence multiple spark electrode arrays are now being developed for 10K to 100K joule systems. The multiple electrode technique has not been fully exploited. However, the following examples indicate the ways the technique may be used to advantage:

By applying a five electrode array to the underwater spark on the *Gosnold*, shallow, folded and faulted structures 10 to 20 kilometers south of Martha's Vineyard were resolved by that system. Such structures first found with the 400 joule system could not be resolved with the spark system on *Gosnold* until resolution was improved by the spark array (Knott and Hoskins, in press).

Use of a triple electrode configuration on the 100K joule spark on the *Chain* increases the output pressure of the discharge pulse about 16 db.

For sound transmission studies in the Baltic during *Atlantis II* cruise 32 the output pulse train (bubble pulse period) of a 12K joule system was reduced from 20 to about 8 milliseconds and the peak pressure of the discharge pulse was increased by more than a factor of two. Resolution of signal arrival times was thus improved and the high frequency content of the output spectrum was increased for the purposes of the sound transmission experiments.

References

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Knott, S. T. and Hartley Hoskins, (in press). Evidence of Pleistocene events in the structure of the continental shelf off the Northeastern United States, *Mar. Geol.*

Knott, S. T. and W. E. Witzell, 1966. Multiple electrode spark source. Patent No. 3,245,032, April 5, 1966, 2 sheets.

SOUND VELOCITY IN THE MEDITERRANEAN

E. F. K. Zarudzki, R. Payne, and E. Levine

Oceanographic data, i.e. the velocity of sound in water and the shallow water temperature structure, gathered during the *Chain* cruise 61, were studied during the summer by Messrs. R. Payne, E. Levine and myself.

This work now nears completion. The findings are contributory to our steadily increasing though still inadequate volume of velocimetric observations. The results appear to agree closely with the velocities of sound computed from hydrographic data. In particular the overall agreement was observed between our velocimetric data and the tables computed and published by the USSR Academy of Sciences (Goncharov, V. P., and O. V. Mikhaylov, 1966).

The thermal sea structure down to the depth of 180 meters was investigated by means of bathythermograph lowerings at two-hourly intervals and by continuously recording thermal probes towed by *Chain* at surface, 5 meters, and 25 to 35 meters depths. Several so far unreported thermal fronts were found to occur in the Ionian and the Levant Seas. The temperature step-ups across these shallow fronts amounted to more than 4°C.

The data analysis is nearing completion.

Reference

Goncharov, V. P., O. V. Mikhaylov, 1966. Depth corrections for changes in the velocity of sound in water for echo-sounding in the Black Sea and Mediterranean. (In Russian). *Okeanologiya, Akad. Nauk, SSSR*, 6 (4): 707-710.

MEDITERRANEAN GEOPHYSICS

E. F. K. Zarudzki

The processing, preparation and initial coordination of geophysical data, obtained during the *Chain* cruise 61 in the Mediterranean, continued through most of the year 1967. The preliminary interpretation of seismic, gravity and magnetic data was commenced in the area of the Sicilian Escarpment and the Ionian Sea. Very interesting relationships were found to exist, particularly between the alignment of magnetic anomalies and the shallow crustal structure. For instance, a positive linear anomalous magnetic trend of the magnitude of 200 gammas diverges approximately east from the front of the Sicilian Escarpment just north of the 35°N parallel.

This trend correlates well with the general morphology of the sea floor in the area (Fig. 1) and with the arrangement of elevated tectonic blocks shown by the continuous seismic profiling (Fig. 2). This newly found relationship may represent a relic continental shelf fragment of early Tertiary age or a remnant Hercynian uplift in the

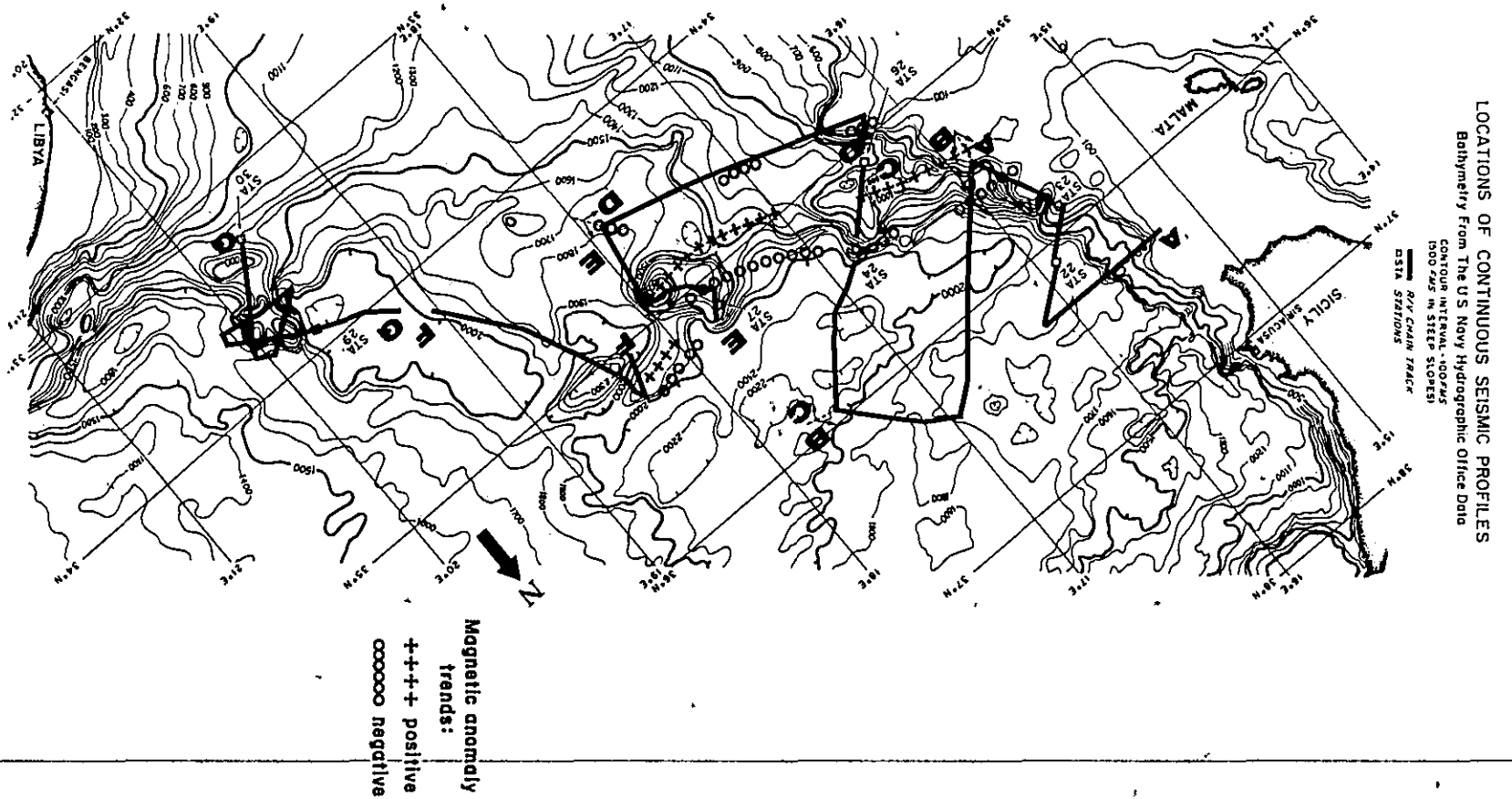

Fig. 1. (Zarudzki) Ship track of the *Chain* during cruise 61 in 1966. Continuous geophysical profiles: seismic, gravity and magnetic, were obtained along the track. The location of anomalous positive magnetic alignments is shown by a series of filled in circles (+); the negative magnetic alignments are shown by open circles (○).

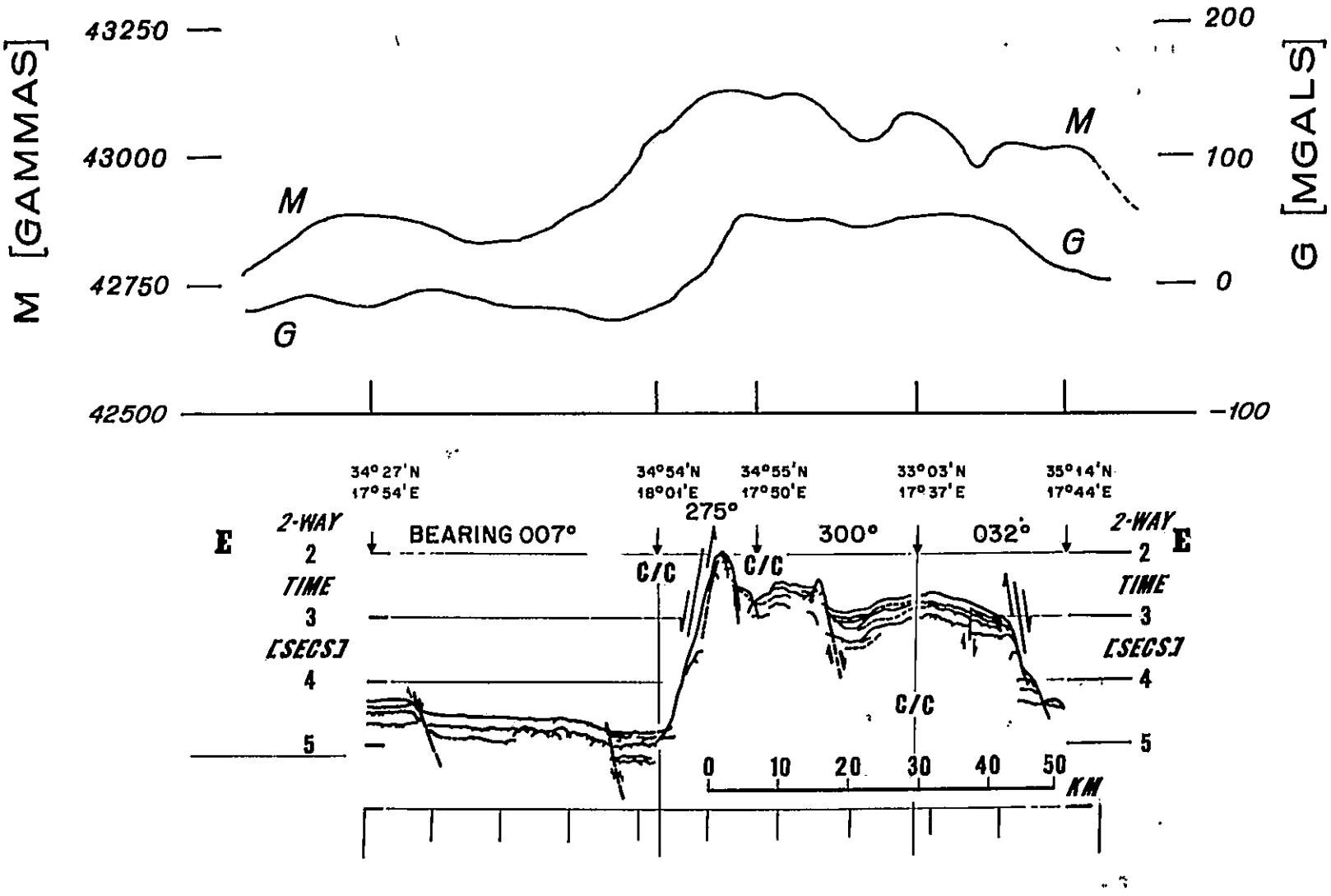

Fig. 2. (Zarudzki). A set of typical geophysical continuous profiles across an up-lifted basement block in Ionian Sea in front of the Sicilian Escarpment. The magnetic and free-air gravity profiles are shown directly above the corresponding, continuous seismic sparker profile. They support the interpretation of an uplifted crystalline basement block in the floor of the Ionian Sea.

Tethys Sea. Proceeding further south the analysis of seismic, gravity and magnetic profiles (Fig. 1, G-G) reveals that the unnamed large guyot with the top at approximately 700 fathoms depth is of non-volcanic origin and probably represents a relic block of African continental shelf.

The interpretation of the Mediterranean data continues.

PHYSICAL OCEANOGRAPHY

DEPARTMENT OF PHYSICAL

OCEANOGRAPHY

Nicholas P. Fofonoff, Department Chairman

INTRODUCTION TO MOORED ARRAY EXPERIMENTS

N. P. Fofonoff and T. F Webster

A program to develop and use instrumented moored buoys for deep-sea measurements of currents and other physical variables has been underway at the Woods Hole Oceanographic Institution since 1960. The scope of the program was expanded in 1966 to permit more intensive operations at sea at a number of permanent sites along the 70th meridian south of Cape Cod.

A rapid advance in instrumentation, data processing and analysis techniques has taken place. Current measurements have been obtained from near surface to near bottom north and south of the Gulf Stream during most seasons of the year. Special numerical techniques for handling the lengthy time series have been developed to provide fast and convenient access to the measurements. A less rapid advance has taken place in improving the performance of moorings at sea. In spite of considerable effort, the recovery of moorings exposed for periods greater than one month remains unacceptably low and precludes deployment of major arrays. The engineering problems involved are complex and progress is hampered by lack of quantitative engineering data on the factors involved in deterioration of mooring components with exposure.

If the potential of the moored-array experiments is to be fulfilled, long time series of measurements, from an array of instruments operating simultaneously, are needed. This can only be achieved if mooring survival can be significantly improved. Because this improvement is so crucial to future scientific goals, during 1967 the emphasis of the program was shifted to the solution of engineering problems. Engineering experiments will receive first priority until mooring reliability and security is assured; it is expected that scientific experiments will be resumed in 1968.

During 1967, most measurements were directed towards obtaining general-purpose, long-term time series, principally at Site D (39°20'N, 70°W). Concentrating efforts at one site has several advantages, among them the development of a statistical description of the spectral "noise background" at the site. This in turn provides a calibrated deep-sea laboratory where a variety of special experiments can be carried out without the need for a basic exploration of that region of the ocean with each new experiment. Several special-purpose scientific experiments were carried out in the region of Site D during 1967. These are reported in the following series of summaries.

In the summaries which follow, reports are presented from scientific, engineering, sea-operations and data-processing groups within the moored array program. The activities within the groups overlap each other and all groups participate in cruises at sea. The following summaries indicate the scope and diversity of activities involved in the program as well as specific results.

Operations with Deep-Sea Moorings

R. H. Heinmiller, J. E. Gifford and G. H. Volkmann

At the beginning of 1967, operations with deep-sea moorings were primarily scientifically oriented. A line of four mooring sites - D, G, H and J (Table 1) - had been established along the 70th meridian. Deep-sea moorings on

TABLE 1
(Heinmiller, Gifford and Volkmann)

Mooring Sites

Site	Latitude	Longitude
D	39°20'N	70°00'W
G	38°00'N	70°00'W
H	37°30'N	70°00'W
J	36°00'N	70°00'W
L	34°00'N	70°00'W
M	33°00'N	70°00'W
P	30°00'N	70°00'W

this line were maintained throughout 1967 by a series of cruises in alternate months. Table 2 summarizes the moorings set during the year. During February and April, the line was extended to Sites M and F. However, by June, because of increasingly obvious engineering problems, a decision was made to temporarily abandon Sites J, M and P and to concentrate efforts at Sites D and L.

TABLE 2
(Heinmiller, Gifford and Volkmann)
Summary of Moorings Set During 1967

#	Site	Mo. Set	Float Type	Duration (Days)	C P L*	Sensor Recovery	Remarks
220	D	Feb	Sphere	58	x - -	6/6	
222	G	Feb	Bottom	> 53	- - x	0/1	Beacon heard 19 Apr; not heard 26 Apr.
224	J	Feb	Toroid	< 3	- - x	0/3	Lost 2 tensiometers
225	M	Feb	Toroid	210	- x -	4/4	Recovered by USS *Hoist;* films exposed.
226	P	Feb	Toroid	1	- x -	4/5	Broke loose; end twisted.
231	D	Apr	Toroid	1	x - -	4/4	Used as navigational aid.
232	D	Apr	Conical	21+	- - x	0/5	Conical surface float.
233	D	Apr	Sphere	---	- - x	0/5	On bottom.
234	G	Apr	Bottom	55+	- - x	0/1	Beacon still heard in June.
235	H	Apr	Bottom	61+	- - x	0/1	Beacon still heard in June.
236	J	Apr	Toroid	---	- - x	0/2	On bottom; off station in June.
237	M	Apr	Toroid	---	- - x	0/4	Beacon heard on bottom in June.
238	P	Apr	Toroid	61	- x -	5/5	Anchor line fouled around release.
239	Shelf	Jun	Boiler	10	x - -	3/3	Internal wave mooring; pressurized subsurface float.
240	No of D	Jun	Toroid	10	x - -	4/4	Internal wave mooring.
241	D	Jun	Aborted		x - -	2/2	Release fired on way overboard.
242	D	Jun	Toroid	51	x - -	6/6	
243	D	Jun	Sphere	52	x - -	6/6	
244	So of D	Jun	Toroid	10	x - -	4/4	Internal wave mooring.
245	G	Jun	Bottom	0	- - x	0/1	Lost after launch.
246	H	Jun	Bottom	52+	- - x	0/1	On station in Aug; release failed.
247	L	Jun	Toroid	---	- - x	0/0	Trial mooring; no instruments.
248	D	Jul	Sphere	0	- x -	6/6	Wire parted during launch; reset as 249.
249	D	Jul	Sphere	8	x - -	6/6	SCOR Site 1.
250	D	Jul	Sphere	8	x - -	5/5	SCOR Site 2.
251	D	Jul	Sphere	7	x - -	6/6	SCOR Site 3.
252	D	Aug	Sphere	9	- x -	3/6	1st try at shear experiments.
253	D	Aug	Toroid	8	x - -	1/1	Test of release systems.
254	D	Oct	Sphere	7	x - -	5/5	Shear experiment.
255	D	Oct	Toroid	1	x - -	1/1	Test of active ground line.
256	L	Aug	Toroid	54	- x -	1/1	Trial mooring; no release.
257	Shelf	Jul	Toroid	1	x - -	2/2	Exhibition mooring.
258	D	Oct	Toroid	1	x - -	1/1	Test of active ground line.
259	D	Dec	10' Conical	5	x - -	1/1	Test of conical buoy.
260	D	Dec	Toroid	2	x - -	6/6	Mooring test with 3 tensiometers.
261	D	Dec	Toroid	1	- x -	3/4	Test of active ground line.
					18 7 11	96/125 (77% sensor recovery)	

\+ Last reported on station
* C = completely recovered, P = partially recovered, L = lost.

In August, further mooring losses, plus the identification of serious engineering problems, prompted a complete reevaluation of the immediate objectives of the program. Because Site D is convenient to Woods Hole, in deep water and clear of the Gulf Stream, efforts were concentrated there, with the emphasis on the engineering aspects of the program. Major scientific objectives were postponed, pending solution of the engineering problems. These problems included troubles with the acoustic-release system, and the complex subject of mooring cables. The fact that mooring recovery had not significantly increased in three years was cause for concern.

As a result, the engineering effort of the project was broadened to investigate mooring problems in a more general way. The October and December cruises were primarily devoted to engineering tests. Some preliminary results from these experiments are described in the summaries which follow.

Instrument Maintenance and Modification

R. H. Heinmiller and G. H. Tupper

Over one hundred sensors of various types and models were placed on moorings during 1967. Current meters accounted for the largest volume of work. Magnetic-tape recording meters have been in use for two years but still have a few problems. Correction of these problems has been given additional impetus by the participation of the Massachusetts Institute of Technology Instrumentation Laboratory in an evaluation program and by the development of tape-reading facilities at the Woods Hole Oceanographic Institution. This program and other tests at Woods Hole have pointed up a series of problems. These included cold temperature condensation on the circuit boards, low battery capacity, inadequate quality control in the mechanical assembly, and design defects in the tape cartridge holder and tape drive. Each of these has been the subject of a corrective program either at the Institution or with the manufacturer.

A number of other types of instruments were maintained, including wind recorders, tensiometers and depth recorders for engineering purposes. Handling and check-out procedures on all instruments have been modified to allow more effective maintenance and better records of instrument performance.

Acoustic Command Releases

R. H. Heinmiller, P. B. Stimson and G. H. Volkmann

The most versatile means of releasing a mooring from its anchor in an all-weather system is by acoustic command.

Within recent months the failure of some moorings has brought into question the reliability of the acoustic release system. A set of tests was run to investigate possible ways in which the releases might not be operating. It was found that the presence of noise spikes, either random or from such regular sources as acoustic beacons will paralyze the release by causing the automatic gain control to drastically reduce receiver gain.

In further tests the integration time of the release was reduced from 2.5 to 1.5 seconds to eliminate the blocking effect of our commonly-used two-second acoustic beacon. Tests were made with and without the presence of a functioning beacon and the system performed well under all conditions. However, the effect of reducing the integration time on the security of the release (accidental release caused by random noise) has not yet been determined.

The effect of varying command-transducer depth was investigated during these tests to determine regions where multipath interference was causing release failures. A mechanical problem which was probably responsible for some past failures has been identified and corrected.

Three other commerically-available acoustic release systems were tested during the year. One feature tested was that of an acoustic indication that a release has received the release command and has acted on it. Results were encouraging and future use will provide more positive information on mooring system performance.

Current Meter Quality Control

J. R. McCullough and G. H. Tupper

Equipment to read magnetic tape cartridges generated by tape-recording current meters, digitizers, etc. has been developed in the Institution laboratory and is now being used to: a) read magnetic tapes generated at sea and b) examine instrument performance before the meters are sent to sea.

The magnetic tapes are coded in a form which, unfortunately, must be decoded before even rudimentary interpretation of the data can be made. The decoding service available commercially has delays (days to weeks) which deaden the impact of ocean experiments and discourage thorough checkout of instrument operation prior to going to sea.

With equipment developed during the past year, current meter tape cartridges with some 150,000 readings can now be processed in 45 minutes. Shorter instrument test tapes can be converted, analyzed and returned in a few minutes. Overall instrument performance can therefore be easily examined. Preliminary experience with instruments previously thought ready for sea (12 tests) revealed minor to major malfunctions which would have contaminated data collected by all of them. The ability to rapidly examine instrument performance provides that level of quality control needed to meet the stringent demands imposed by experiments using arrays of instruments.

Current Meter Evaluation

Massachusetts Institute of Technology Instrumentation Laboratory

Reviewed by R. G. Walden

During the past year the Massachusetts Institute of Technology Instrumentation Laboratory has participated with the Woods Hole Oceanographic Institution in a joint program designed to examine, test and evaluate the Geodyne tape-recording current meter to increase the effectiveness and reliability of this instrument in the moored buoy program. To identify and determine the environmental conditions and forces under which the current meters must perform, a series of experiments were carried out at sea from the *Chain* in August.

An instrument was developed, Ocean Environmental Sensing Equipment (OESE), similar in size and shape to a current meter, to measure the environmental forces acting upon the instrument. Body motions, forces and acceleration as well as cable tension and current speed were recorded under a wide range of conditions. These conditions included a Stimson anchor drop experiment where the instrument, connected above the anchor, measured and recorded the forces imparted to it during the anchor launch. While attached to a simulated deep mooring cable towed by the vessel at various speeds, the instrument recorded superimposed line vibration and acceleration modes ranging in period from 30 milli-seconds to 40 seconds. The maximum angular rate of rotation of the case about its axis was 180°/second, the maximum accelerations noted were 1.5 G's and the maximum dynamic tensions were not over 5,000 pounds. Tests were also conducted using the instrument attached to a toroid surface buoy being towed to approximate the conditions experienced during deployment of a mooring.

Engineering data accumulated from these tests are being used to specify environmental conditions for design, evaluation and test criteria of instruments used in the deep-sea moorings. Likewise the data will be useful, when completely processed, to indicate dynamic tension values and vibration frequencies and amplitudes present in the upper sections of mooring cables.

The data obtained from these tests were used to develop a laboratory environmental simulation test of the magnetic-tape current meter. Defects in design and production were noted through mechanical vibration and temperature cycling. Detailed recommendations have been supplied both to members of the Institution and the manufacturer concerning improvements in design and manufacture. A quality and acceptance test procedure has been specified which, if adopted, should reduce the number of malfunctions of these instruments at sea.

Instrument Development

Paul B. Stimson

Numerous recordings of mooring cable tension have been taken over the past several years. In general, the records have been recovered only from the successful moorings; the loss of data from stations which went adrift has been a continuing source of frustration. A system of cable tension telemetry has therefore been designed, and has come into general use during 1967. Night-time reception over distances as great as 700 miles has been achieved, using only 2 watts at 2398 KHZ. The telemetry encoder is being modified so as to transmit surface current speed and direction as well.

Cable tensions continue to be recorded at the buoy. During the year, a pressure-compensated tension transducer was developed; it is now possible to record tension at selected depths along the cable.

A depth telemetry device has been developed, and was installed and tested in one of our standard acoustic beacons. It makes possible the measurement of rates of ascent and descent of elements of the mooring system, and has already produced valuable new data.

Other developments include a 4-inch diameter tape transport with 10,000-foot tape capacity, an endless-loop 16-mm. instrumentation camera with more than 300-foot capacity and a new line of solid state timing devices with an accuracy of 5 parts in 10^6 for use in current meters, acoustic releases, etc. All are nearly ready for sea trials.

Mooring Systems

H. O. Berteaux and P. B. Stimson

Engineering efforts have concentrated on a better understanding of the causes and modes of failures of the mooring lines of deep-sea buoys and on the improvement of their design. In early 1967 computations and measurements made at sea confirmed the need for increasing the size and ultimate breaking strength of the wire rope used in surface moorings. A new type of mooring line was assembled having higher strength and more corrosion protection. A total of 16 moorings, 7 long term (2 months) and 9 short term (2 weeks maximum) were set in 1967, using this new type of mooring. The short term moorings were 100% successful, but only two of the long-term moorings were retrieved out of seven set. These and other mooring failures have emphasized the need for the vigorous engineering program now being pursued.

An informal panel composed of participating engineers and metallurgists from the Massachusetts Institute of Technology, the Pre-formed Line Products Company and the Bergen Wire Company was formed during 1967 to examine the ends of wires retrieved from failed moorings.

Because of continuing evidence that corrosion plays some role in the failure of mooring cables, new corrosion-resistant alloys are being investigated. These materials have mechanical properties similar to those of steel, but their corrosion rates are at least two orders of magnitude lower.

Tests of an "active ground line" which will bring back to the surface portions of moorings which have failed were made. Operational difficulties have been encountered. Further tests will be made in 1968 using a buoyant ground line and a release above the main anchor.

A newly-designed surface float has been built and tested. It is of conical shape, 10 feet in diameter and 4 feet high, of foam-filled welded aluminum. Its 7-inch diameter by 12-ft long aluminum mast houses the buoy's power supply, instrumentation and transmitter, affording good protection from the elements. The buoy has been observed at sea in heavy weather, and appears to ride well. A previous experience with a similar (but smaller) buoy, with a current meter at 10-meter depth showed high noise level. Measurements taken with the new buoy will be used to examine the nature and source of the noise.

Buoy Data Processing

John A. Maltais, Susan A. Tarbell and Marie Andrade

During 1967, seventy-two sets of digital time-series from instruments set on the 70°W meridian were processed. In addition, non-digital pressure and tension data were processed, as well as digital data from other groups and institutions. The time-series processed from 70°W were produced by several types of instrument: 32 were from film-recording current meters, 22 from tape-recording current meters, 7 from tape-recording current-temperature meters, and 11 from film-recording wind recorders. These data alone represent a collection of more than 7 million samples.

This past year marked the first extensive use of tape-recording current meters. New computer programs to process the data produced by these instruments were created. Further programming effort included simplifying user access to standard magnetic tape data files, increasing capabilities for identification and removal of errors from data, providing additional graphical facilities, and application of new statistical analysis procedures.

The buoy data-processing system has been improved to simplify its use. Plans have been made to improve and generalize the format of permanent data storage on magnetic tape. These plans will be put into use when the Institution's new computer arrives in 1968. The new format will not be restricted to current meter data, but will accommodate a broad range of oceanographic data.

Digital Filtering of Ocean Records

James McCullough

Digital computer "filters" can be used in the same manner as mechanical, electrical and optical filters to partition observed signals into populations with different frequency characteristics. The primary advantages of such digital filters are flexibility and ease of application to computer-oriented data records.

Filter programs have been developed this year and are now being used to: a) separate inertial and tidal energy from the larger low-frequency energy of deep-ocean current records, b) fit "smooth" curves to "noisy" data (expendable bathythermograph records and ocean wind records), c) remove frequency bands with high energy content in order to make more reliable spectral estimates at other frequencies (vertical ocean currents) and d) search voluminous data records for questionable data points. The digital filters exist as individual computer program modules that are readily accessible to other programs. A set of special auxiliary programs has also been developed to allow routine filtering of data recorded in the format used for moored current meter data.

Internal Waves of Tidal Period

N. P. Fofonoff

The continental shelf converts tidal motion into internal waves that are propagated across the slope into the interior of the ocean. Simple theory suggests that the motion and energy flow are along surfaces inclined to the horizontal at an angle that is determined by the wave frequency and the local Brunt-Väisälä frequency. These are referred to as "characteristic" surfaces. Flow of energy from the continental shelf in the form of internal waves of tidal period is limited to characteristics that connect to the shelf. These are shown in Figure 1, based on hydrographic data from Site D. Little reflection occurs from the slope itself because the characteristics are approximately parallel to the topography.

A pilot experiment to detect tidal internal waves was carried out in June, 1967 with three short-term moorings set across the continental slope north of Site D (Fig. 1). Tidal currents on the shelf were weak (10 cm/sec) while motion off the shelf was dominated by inertial currents at all depths so that tidal components could not be resolved. The experiment needs to be repeated over a longer period of time to eliminate transient inertial components.

As part of the experiment, instruments to measure temperature as well as currents were placed on the moorings. Temperatures were measured at the top and bottom of the pressure case (a vertical separation of 1.5 meters). In Figure 2, two records of temperature and current direction are compared. The current is predominantly inertial in the last half of the records and is approximately in phase at the two moorings. Tidal periodicity is clearly recognizable on the shelf in both temperature and current direction. Off the shelf, the variation of temperature is more complex, although the inertial component in the direction is recognizable. The mean currents across the slope are opposite in direction indicating a complex flow structure over the continental slope.

Spatial Scales of Inertial Motions

T. Ferris Webster

Measurements with moored current meters have shown that inertial-period motion is a dominant time-dependent phenomenon. Such motions have a transient nature: their amplitude may increase by a factor of ten within three or four inertial periods; this maximum intensity may be short-lived; they can in turn die out within a few periods. The means of generation, propagation and decay is not well understood.

Observations made over a simple array at site D (39°20'N, 70°W) have been used in a study of the scales of spatial coherence of inertial-period motions. Using series of measurements collected simultaneously at pairs of instruments over a six-week period, the coherence of inertial motions over a horizontal separation of 3 km and over a variety of vertical separations has been determined. It is found that the coherence of inertial motions over vertical distances greater than a few meters is small. That is, while such motions are highly coherent over two meters vertical separation, over an 80-meter vertical separation (determined from measurements collected at 7 m and 87 m below the surface) the coherence drops to the point where it is barely significant. No significant coherence was found over a vertical separation of several hundred meters. Over a 3 km horizontal separation, however, the coherence is relatively high.

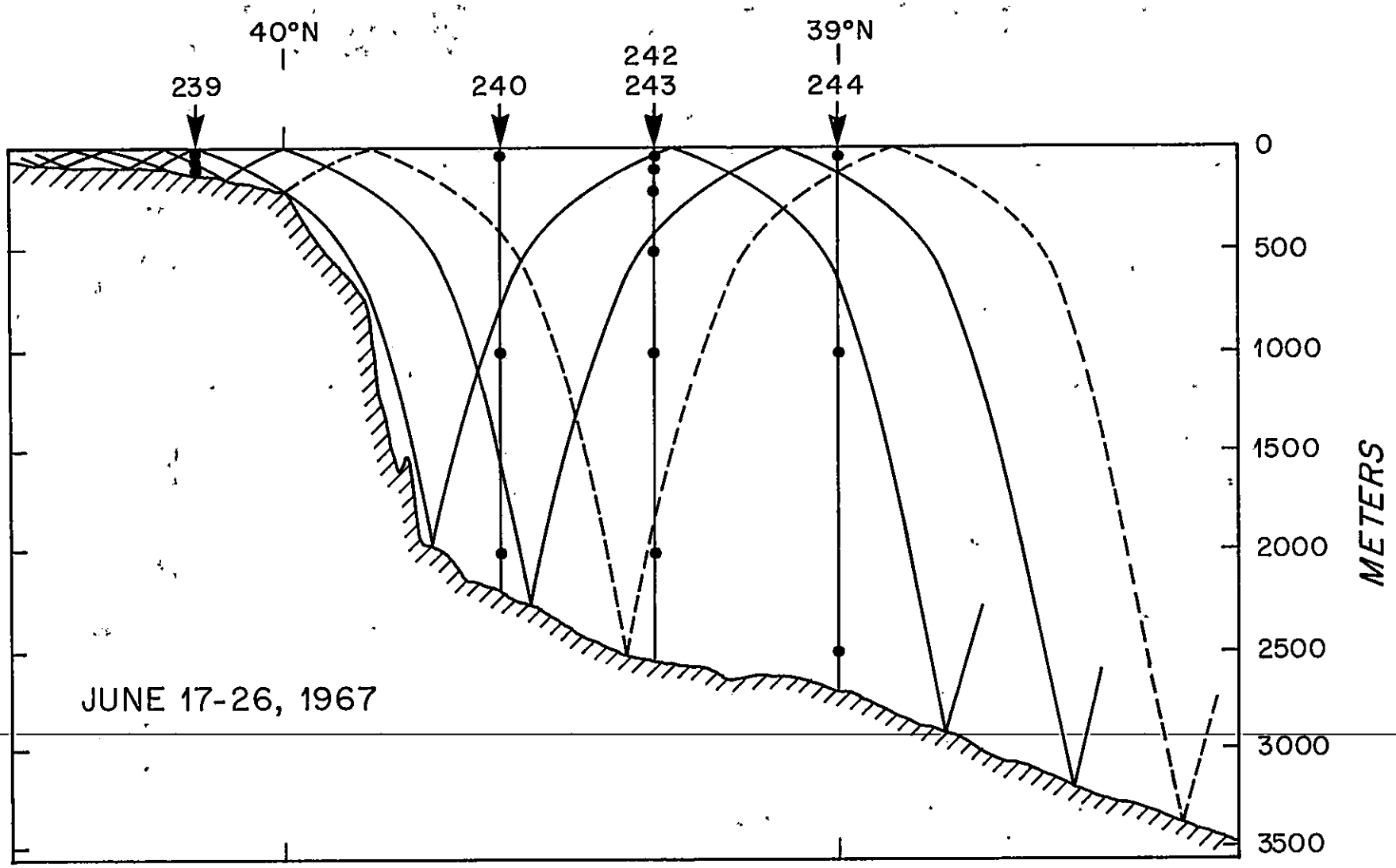

Fig. 1. (Fofonoff) a profile along 70°W showing the distribution of characteristic surfaces connecting to the shelf for internal waves of tidal period. Short-term moorings 239, 240 and 244 were set to compare tidal current amplitudes in and out of the region bounded by the characteristics. Moorings 242 and 243 were long-term moorings at Site "D" set during the same period.

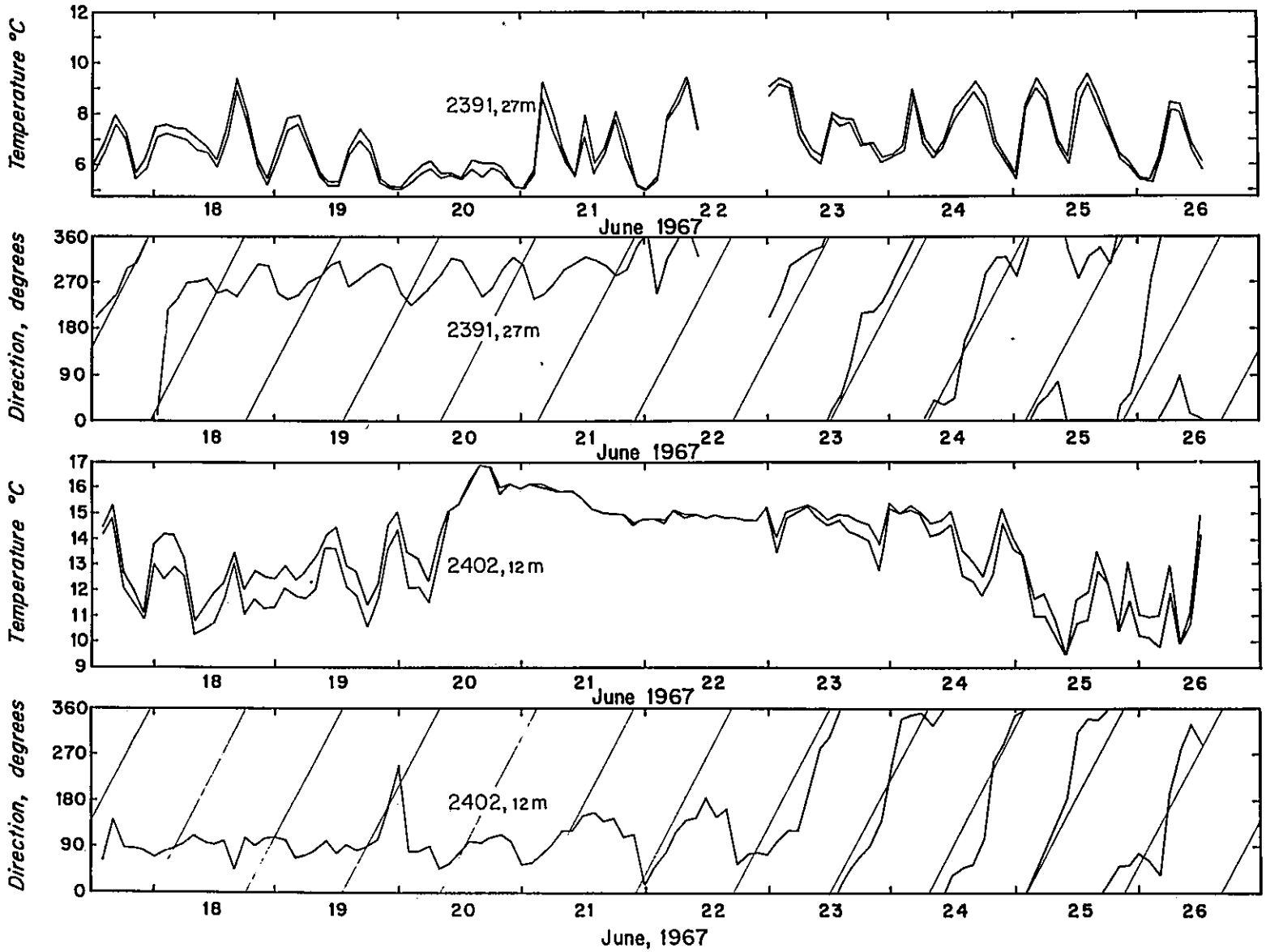

Fig. 2. (Fofonoff) Temperature and current direction records from mooring 239 and 240. The moorings are 33 nm apart at locations shown in Fig. 1. Temperatures are plotted from two hour averages of readings from the top and bottom of the recording instrument. The current is measured at the bottom of the instrument. The slanted lines in the panel showing directions represent the angular rate for a uniform inertial current. The depth of the instruments in meters is indicated in each panel.

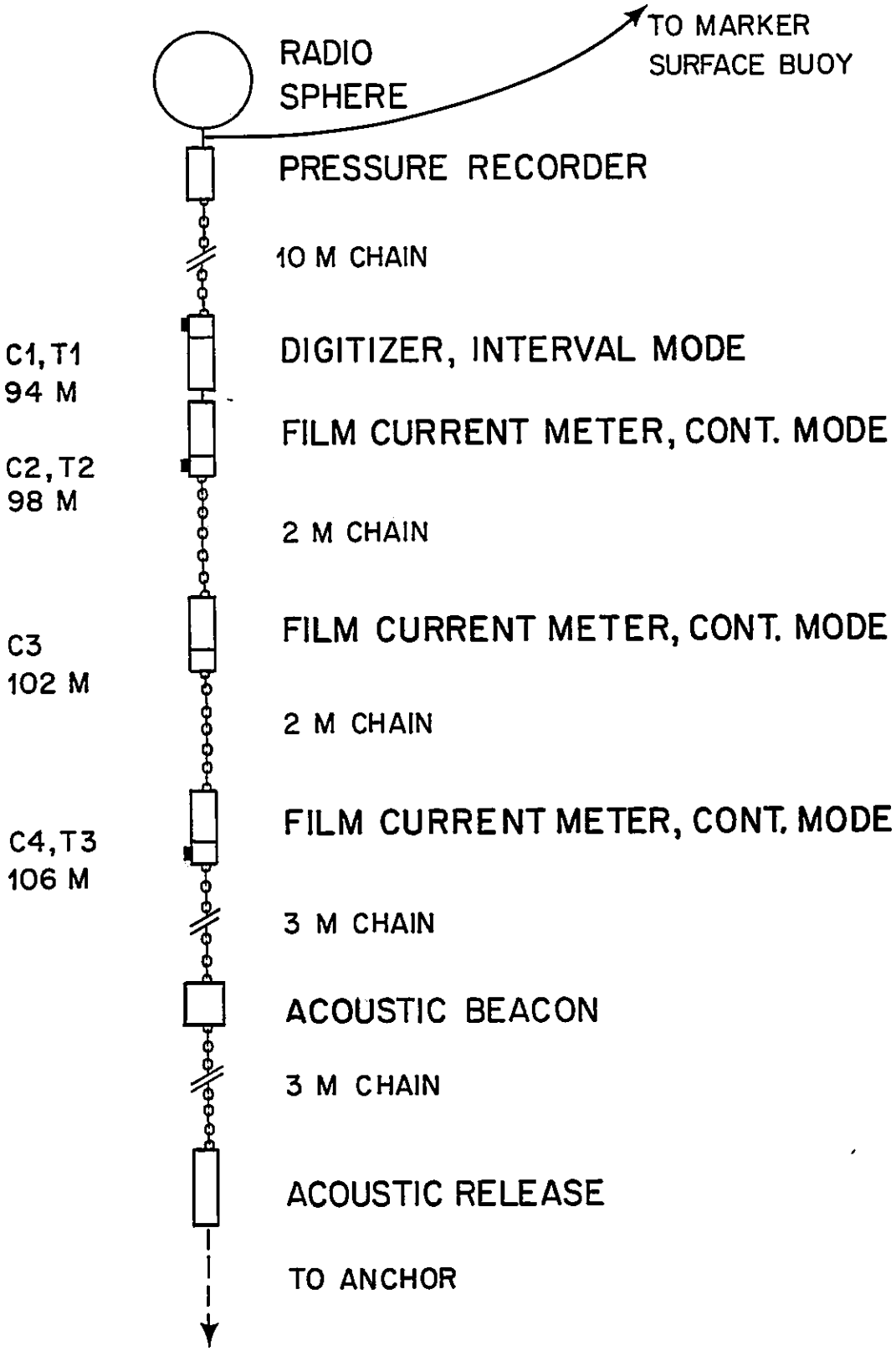

Fig. 1. (Siedler) Instrument array for small scale shear measurements (current sensors C_1 to C_4; temperature sensors T_1 to T_3).

The pattern of coherences is consistent with the hypothesis that inertial motions have shallow vertical extent. This is not to say that their influence penetrates only a shallow surface layer; they have, in fact been observed at all depths including near the bottom. Their structure, rather, has a constricted vertical extent: though at any time, inertial motions might be found at many depths, the motions become incoherent as the vertical separation exceeds a few tens of meters.

While the results obtained from the experiments carried out so far have provided only an incomplete picture, they have stimulated some fresh theoretical studies. Further experiments over more intensive arrays are needed to provide the description for more effective models.

Measurements of Small-Scale Vertical Shear

Gerold Siedler

Measurements with moored instruments have shown great differences in current speed and direction over short vertical distances. To obtain information about the structure of small-scale shear and its relation to the density field, an experiment was carried out using a special instrument mooring. An array with four current meters each four meters apart and several temperature sensors was designed. Unfortunately, the first attempt to use this mooring in August, 1967 was not successful. Three instruments of the array were lost during the recovery because both acoustic releases in the system failed to operate properly. The experiment was repeated in October 1967 with a slightly changed mooring design. One digitizer, measuring currents and three temperatures at 15-minute intervals, and three film-recording current meters in the continuous mode were combined in the array (Fig. 1).

The mooring was set at site D at 39°21′N, 70°03′W on October 3, 1967 in a depth of 2620 meters and was successfully recovered on October 10, 1967. At the beginning and the end of the measuring period, repeated expendable BT measurements and hydrocasts were carried out. Closely-spaced water bottles were used in the depth range occupied by the array. This depth of about 100 meters had been selected as a compromise between two requirements. The array should preferably operate at a level deep enough that density determinations might be possible in a rough approximation from the temperature measurements, and it should be high enough to find a shear sufficiently strong to avoid problems caused by the limited accuracy of the speed measurements.

The data have been processed, and it was found that some editing was necessary because of inaccuracies in the time scales of the individual time series. Most of the data are usable and will be analysed in 1968.

Miscellaneous Measurements

Robert C. Millard, Jr.

In addition to measurements of currents and temperature, related measurements of wind, pressures (depths) and mooring tension have been collected. These latter types of observation are useful both for scientific and engineering purposes. Because of the recording format, special handling of the records is usually required.

Tensiometers have been installed below the surface float on several moorings in order to study long-period variations in mooring tension. The records show two classes of variability in the tension: (1) wave induced scatter and (2) long period variations.

Typically, a mean tension of 800 lbs. near the surface shows a long-period variation with perhaps an amplitude of ± 200 lbs. These variations appear to be correlated with variations in the strength of the currents. However, calculations do not produce a significant correlation. A better synchronization of the time bases between the two instruments may improve the correlation. A further study is planned to compare the amplitude of the wave-induced scatter with local wind strength.

Wind recorders are standard on moorings having surface floats. Although the sampling procedure for current meters had been investigated several years ago, a corresponding study of the procedures for sampling winds had been neglected. Several high-sampling-rate wind-recorders were used to provide data for a study of sampling procedures.

The problem is one of spreading out a limited number of samples (180,000) over a long time interval (60 days). This set of samples allows the spectrum of variability to be determined over a specific range of frequencies. The optimum sampling procedure minimizes the contamination of the true spectrum within this range by processes at high frequency outside the range.

An exploratory spectrum covering periods from 1 second to 20 days was computed using data from both low- and high-sampling rate wind recorders. The degree of contamination in a set of hypothetical sampling procedures was then determined. It was found that for a cut-off period of 1/2 hour the optimum sampling rate is simply once every 30 seconds.

Pressure recorders are used on moorings with sub-surface floats in order to determine the absolute depth of float and instruments. Generally, variations in depth are slight. Occasionally, wide variations in depth of the mooring have been observed. The causes of these variations is not yet fully understood and further study is proposed.

Electromagnetic Measurements

Thomas Sanford

Natural electromagnetic fields in the sea arise from external sources, principally ionospheric disturbances and from internal sources, the motion of sea water through the geomagnetic field. The present investigation is confined to the latter source and seeks to determine: (1) to what extent the motionally-induced electric field can be used as a reliable indicator of the motion of the sea and (2) the interpretation of the electric and magnetic fields in terms of the electrical conductivity of the ocean and solid earth.

In order to gain insight into these problems, a theoretical study has been underway into the induced electric (E) magnetic (B) fields associated with a 3-dimensional, time-dependent (ocean) flow in an ocean of non-uniform depth. The analysis shows that for low-frequency (periods greater than several hours), large-scale (compared with the ocean depth) motion the horizontal electric field is governed by a local effect proportional to the vertically averaged velocity and a large-scale effect representing the electrical interaction of distant velocity or source fields. The latter effect did not arise in previous steady, 2-dimensional investigations. The consequences of the second effect are that electrical measurements in large-scale flows, such as the tides or the Gulf Stream, will be significantly influenced by the character of the flow far from the point of observation and that due to this interaction magnetic fields will arise. The coupling of the E and B fields reflects not only the character of the flow but also the electrical conductivity structure of the ocean, crust and mantle.

In summary, the investigation has advanced the interpretation of motionally induced electric and magnetic fields in the sea. We are now better able to interpret electromagnetic measurements in terms of the motional patterns of the sea and the electrical structure of the earth. As a result, observational programs are now being formulated to utilize E and B measurements in the deep sea.

Vertical CCTD (Current-Conductivity-Temperature-Depth) Profiles

N. P. Fofonoff

In February 1967 a unit to obtain vertical profiles of current, conductivity, temperature and depth (CCTD) was delivered by Geodyne Corporation for shipboard use in conjunction with cruises to set and recover moorings. The unit consists of a lowered sensor package connected by cable to a deck recording, display and playback system. The unit is designed to be compatible with moored instrumentation and can be used to read and display magnetic tape records recovered from moorings.

A total of 27 stations have been made to date. The maximum depth reached was 4000 meters, although most stations were shallow (500 m or less). The primary use of the unit has been to examine vertical and horizontal scales of microstructure within the upper layers. The velocity measurements provide estimates of the horizontal movement of the instrument through the layer being sampled. Measurements near site D (39°20'N, 70°W) yielded horizontal scales of 200-300 meters for inversion layers at a depth of 70 meters. More extensive work to examine velocity shear layers and their associated temperature structures near the surface is planned during 1968.

Florida Current Dynamics

William Schmitz

In 1967, efforts to establish an observational basis for testing hypotheses on the dynamics of the Florida Current were extended downstream from the Florida Straits to Jacksonville. The author has been participating in

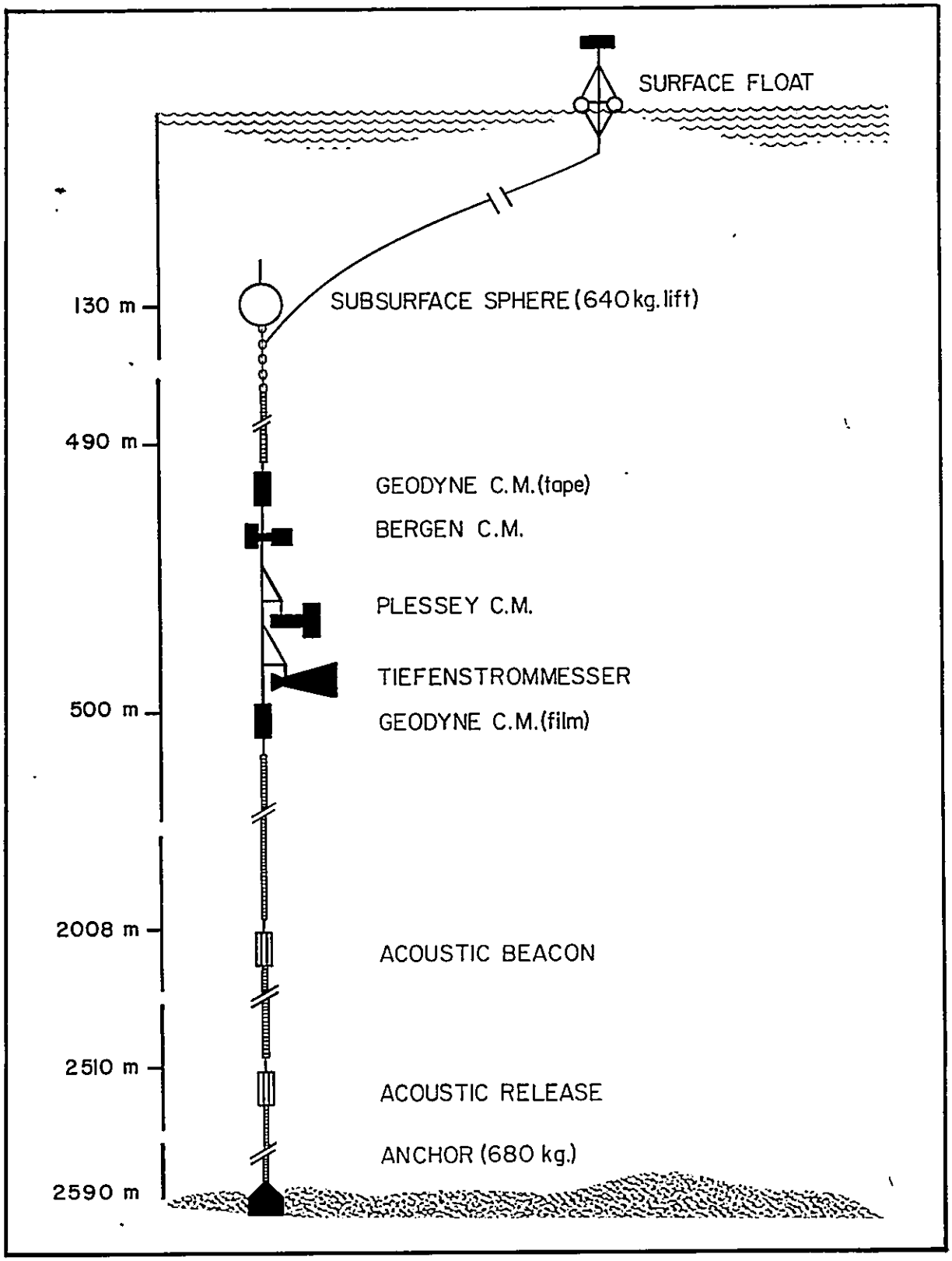

Fig. 1. (Fofonoff and Siedler) Mooring for current meter intercomparison.

this project with W. S. Richardson and P. P. Niiler (at Nova University, Fort Lauderdale, Florida). Simultaneous mass and velocity field measurements using the free-instrument method were collected at two sections across the current near Cape Canaveral and across one section off Jacksonville. A typical section consists of from one to five free-instrument drops at each of about 15 stations. From ten to twenty such transects were run over a one to two month period at each section.

Three dimensional representations of the mass and velocity fields in the current have been formed from 1965-1966 data at four sections across the current. Potential vorticity-streamline distributions have been calculated. The testing of various hypotheses on the mean-current dynamics on the basis of this data is currently being pursued in conjunction with P. P. Niiler.

Transport measurements have been accumulated over a three year period (Summer 1964-Summer 1967), about sixty transects across the current. The average transport is $32 \pm 3 \times 10^6 m^3$ sec. Monthly averages lie within this bound and are reproducible. The total fluctuation amplitude is $12 \times 10^6 m^3$/sec. Tidal amplitudes for M_2, K_1 and O_1 are $3.5 \pm 1 \times 10^6 m^3$/sec. There is no evidence in this data for fluctuations at non-tidal periods of amplitude greater than 10% of the mean current.

Intercomparison of Current Meters

Nicholas P. Fofonoff and Gerold Siedler

Within the framework of the program for measurements from moored buoys, an intercomparison of current meters has been carried out by the SCOR Working Group 21. The measurements were done partly at the Institution and partly aboard the R.V. *Gosnold* during the period July 6 to August 1, 1967. The following members of the group were present: N. P. Fofonoff, T. Kvinge, G. Siedler, J. C. Swallow.

The aim was to make an intercomparison of some of the principal current meters presently in use by calibrating them in a tow tank and by putting them out in closely spaced moorings. Three of each of the following types of current meters were available: Geodyne (tape recording), Geodyne (film recording), Bergen, Tiefenstrommesser (TSM) and Plessey. As the members of the working group from the Soviet Union, K. A. Chekotillo and B. Shekhvatov unfortunately were not able to attend, the Alekseev meter could not be included in the measuring program.

Several tow tank trials were aimed at determining the shape of the speed calibration curve and threshold speeds for each type of current meter. The Bergen, Plessey and TSM instruments were calibrated at about a dozen speeds in the range 2-35 cm/sec, though the size of the TSM compared to the tank made the absolute value of its calibration doubtful. Some crude visual measurements were made, with each meter, of the acceleration of the speed sensor when released from rest while being towed at various steady speeds. Calibration runs were made on only one Geodyne rotor, since this sensor had already been studied earlier in great detail by Fofonoff and Ercan. Check calibrations were made on one Bergen and one Plessey meter after the instruments had been used at sea.

The mooring work was carried out near site D (39°20'N, 70°00'W) from R.V. *Gosnold* because many current meter records were already available from this region. In addition, the two long term moorings 242 and 243 were in position during the intercomparison period. Three special moorings with five different current meters each were laid on July 16 and 17. The mooring configuration is shown in Fig. 1. With two types of current meters being bracket mounted, it was preferred to launch the moorings anchor-first contrary to the anchor-last method normally applied by the buoy group. During four days several observations of temperature, conductivity, pressure and relative current were made with a lowered sensing digitizer (CCTD) through the depth range occupied by the current meters. Water samples were taken during some lowerings. All three moorings were successfully recovered on July 24.

Data Processing began immediately after the field work was finished. Some preliminary analyses were made using standard programs of the buoy group and some special programs for converting from Bergen, TSM and Plessey format to Institution format. All the analysis work was done with the help of T. F. Webster and J. A. Maltais.

It was found that not all current meters had worked satisfactorily, but is is expected that useful data can be obtained from more than half of the meters. Data checking, editing and analyzing have been carried out in Woods Hole as well as in Bergen, Norway and Wormley, England. At the end of 1967, the Bergen and TSM data and some Geodyne data were edited and analyzed by histogram, time histogram and progressive vector diagram computations. The Plessey data are being processed now at the National Institute of Oceanography in England. When all usable data are edited, further detailed analyses will be done.

VERTICAL MOTION IN SLOPE WATER OFF NEW ENGLAND

A. D. Voorhis

In recent years there has been an extensive program here to study the spectra of horizontal motion in the open sea using data from current meters at permanent moorings. We have felt that equally detailed measurements of vertical motion would complement these studies and shed some light on how the energy in the sea is partitioned between horizontal and vertical modes of motion. This past year we have used a new instrument, developed here by D. C. Webb, to measure directly vertical motion in the slope water off New England.

The instrument is a neutrally buoyant rotating float which is, in many ways, similar to the Swallow float now in use here and elsewhere. It consists of a 10-inch hollow glass sphere below which is suspended an acoustic projector. Fitted around the sphere's equator is an array of tilted vanes. The entire instrument is ballasted and launched in the usual manner to sink to a predetermined depth. After it has reached its equilibrium depth slow vertical currents, such as those produced by internal waves, generate relative flow past the vanes causing the instrument to rotate. This rotation is detected relative to a magnetic compass within the sphere and transmitted acoustically to a nearby ship at the surface. With suitable calibration the vertical motion of the water can be calculated from the float rotation.

Last April several of these floats were launched within and beneath the permanent thermocline of the slope water near 39°N, 70°W. The water depth in the area was about 2600 m. In most cases we could follow and record the float rotations continuously for periods of three to five days. Shown in Figure 1 is a 48-hour portion of the rotation record of a float launched at a depth of 725 meters. Positive rotations in the figure mean that they are clockwise when viewed from above. From this record one can determine that the water was moving up and down slowly as much as 50 meters with velocities less than 1 cm/sec. The period of fluctuations varied but was usually greater than 30 minutes. The spectrum of the vertical motion was calculated and compared with the spectrum of horizontal motion measured from current meters at a nearby moored array. This showed that there was an approximate equipartition between kinetic and potential energy over a significant portion of the frequency spectrum. It also showed that the water particles were approximately moving in elliptical paths, where the minor axis of the ellipse was vertical. The ratio of minor to major axis depends on frequency but was as large as 2/3.

Present plans are to continue these measurements in 1968 in the Sargasso Sea near Bermuda. In this area we can expect a deeper permanent thermocline and a more interesting spectrum of vertical motion.

SALINOMETERS

Karl E. Schleicher

Work on the measurement of the thermal expansion of sea water occupied most of my time during the year. This study is being done in collaboration with Mr. Alvin Bradshaw.

Other work undertaken during this past year included further improvement of the WHOI salinometers and the development of a simple salinity analog computer.

In the fall of 1966 UNESCO and the National Institute of Oceanography of Great Britain published a set of tables (International Oceanographic Tables) giving the salinity of a water sample as a function of the ratio of its conductivity to that of a water sample of 35‰ salinity at 15°C. This table and the equations expressing the above relationship was recommended by the Joint Panel on Oceanographic Tables and Standards (a UNESCO committee) for the new definition of salinity.

The three Mark 3 WHOI salinometers have been recalibrated according to the UNESCO equation during this past year. At the same time some changes were made on the instruments in order to improve their accuracies, particularly below 30‰. The salinometers have been calibrated over their entire workable range which is approximately 0 to 50‰. [The UNESCO tables go from 2.8‰ to 42‰; therefore the salinometer calibrations above and below these values are based only on an extrapolation of the UNESCO equations]. As a check on the bridge accuracy, decade resistances were substituted for the conductivity cells and a series of 21 resistance ratios were run on each salinometer. With but two exceptions the differences between the measured and actual ratios for the total 63 points were not more than the salinity equivalent of ± .001‰ for the 30‰ to 40‰ ranges and ± .01‰ for the 0‰ to 30‰ and 40‰ to 50‰ ranges [calibrated only to .01‰]. The two exceptions were a difference of .02‰ at about 19‰ in one salinometer and a .002‰ difference at about 38‰ in another instrument.

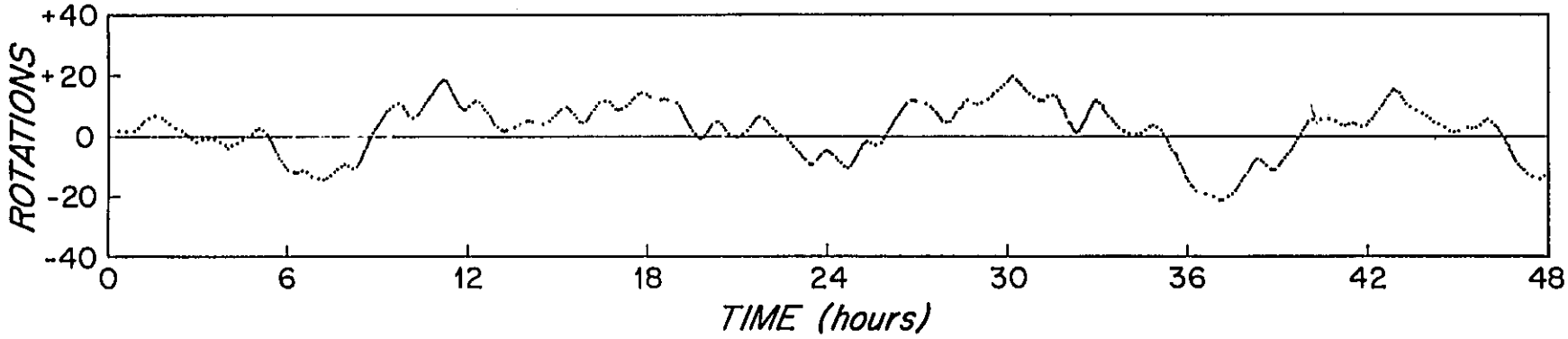

Fig. 1. (Voorhis) Float rotation showing vertical motion.

Due to the recent purchase by the Institution of several *in situ* conductivity-temperature-depth instruments, interest has been revived in the development of a simple, moderately accurate, salinity computer so that the output of these instruments can be monitored in terms of salinity on board ship. In the autumn of 1963 the basis for such a computer was worked out but its further development was discontinued since work was stopped on the particular instrument with which it was to be used. During 1967 the development of the computer was continued and a satisfactory bread-board model constructed. The basic computer is extremely simple, should be quite cheap to make and should prove useful for other applications such as for a simple, manually operated desk computer.

THERMAL EXPANSION OF SEA WATER

A. L. Bradshaw and K. E. Schleicher

The temperature derivative of the specific volume of sea water at constant pressure enters into the computation of a number of quantities whose values are required by the physical oceanographer. One of the most important of these is the adiabatic temperature gradient. This quantity is used in studies of the completeness of mixing (in deep basins) and in calculating the stability and the potential temperature. Presently used values of the temperature derivative of specific volume are derived from the measurements of Ekman (1908) on the compression of sea water at different temperatures and salinities. Their accuracy was questioned by Eckart (1958). Since then a number of investigations have been made in attempts to settle the question raised by Eckart. The method used in the present investigation differs from previous ones in that it involves the direct measurement of thermal expansion instead of its derivation from measurements of compression (Ekman, Newton and Kennedy, and Wilson) or sound velocity (Crease). We believe that it is capable of giving greater accuracy.

The apparatus used for this method consists of a fused quartz dilatometer in which a change in sample volume is amplified to a change in length in a small, precision-bore tubing. An iron float rests on mercury which is in the tubing and which connects with the sample volume. The position of the float is followed from outside by a null-operated differential transformer which is coupled to a micrometer head.

During this year the dilatometer volume was calibrated as a function of temperature and pressure using mercury, the P-V-T relationship of which is known very accurately. Thermal expansion runs were then made on distilled water at low and high pressures. The results agreed with the apparently very accurate ones of Kell and Whalley (1965) within their limits of accuracy. Next measurements were made on $35‰$ salinity sea water from -2 or 0°C to 30°C in 2°C steps at pressures of 7 (incomplete), 500 and 900 bars. The thermal expansion coefficients derived from the latter showed much closer agreement with those of Ekman and Crease than with those of the remaining investigators. Within the range of pressure and temperature of Ekman's measurements (1 to 600 bars, 0 to 20°C, respectively) the agreement was within 6×10^{-6} $(°C)^{-1}$.

From an analysis of the method and the results that have been obtained so far, we estimate the accuracy to be better than 2×10^{-6} $(°C)^{-1}$ and the precision (standard deviation) to be 0.3×10^{-6} $(°C)^{-1}$.

During the last run made we discovered a temperature effect in our system of measuring the change in length of the mercury column. It affects the measurement of the temperature coefficient of volume change by an estimated 1 to 2×10^{-6} $(°C)^{-1}$. Since it was also present during the calibration against mercury, it should have no effect on the results. We have eliminated it, however, and we plan to redo the runs previously made. The complete set of measurements will be on $31‰$, $35‰$ and $39‰$ salinity sea water over the temperature range -2° or 0°C to 30°C at several pressures from 1 to 1000 bars.

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A CYCLONIC RING FORMED BY THE GULF STREAM

Frederick C. Fuglister, Charles E. Parker and Marvel C. Stalcup

While tracking the Gulf Stream on March 1st, 1967 the U.S.N. Oceanographic Air Survey Unit observed a large meander near 65°W. Five subsequent flights, the last on April 6th, showed that this meander became detached from the Stream to form a large ring, or elongated cyclonic eddy, in the Sargasso Sea. A temperature-depth profile to 450 m was made across the eddy from the *Crawford* on March 21st and on the April 6th flight, with air-dropped BTs, a temperature-depth profile to 300 m was made along the short axis of the eddy.

On May 3rd the *Crawford* began a series of eight cruises to track the movement of this eddy. On these cruises surface floats were drogued with parachutes at depths from 10 to 500 m and neutrally buoyant floats were placed at depths from 500 to 4,000 m at various positions in the eddy.

The 100 m drogues worked remarkably well, not only serving to relocate and identify the eddy but producing over 3000 hours of current trajectories in the cyclonically rotating ring. The neutrally buoyant pinger floats were followed for a total of 935 hours. The trajectories of these various floats were complex and interesting, as might be expected when we consider the spatial variation of current speeds found within the cyclonically rotating eddy and the fact that the whole was itself translating in an anticyclonic path. An example of current trajectories is shown in Fig. 1.

Even with the hundreds of miles of current trajectories, continuous surface temperature and salinity records, continuous 200 m temperature measurements, nearly 2,000 deeper temperature observations and 53 hours of infrared measurements from our aircraft, there remain puzzling aspects about the simple geometry of this Gulf Stream ring. At times it appeared to be a circular ring translating at a fairly uniform speed but then it would slow down or speed up, and the trajectories cannot be resolved unambiguously into a combination of rotation and translation.

Even in the early stages, when the observations were from the aircraft and the whole surface aspect was mapped in a few hours (so that the displacement of the whole eddy was insignificant) the eddy had a very irregular shape that was difficult to associate with any sort of simple rotation.

A total of 30,583 miles was covered by the *Crawford* and the *Atlantis II* on the nine eddy cruises in 1967. On the final cruise in Nobember no marker buoy was found and it appeared that the eddy had moved into and become reabsorbed by the Gulf Stream.

A thorough analysis of this mass of data will take considerable time but should result in a new insight into the kinematics of these cyclonic rings formed by the Gulf Stream.

SALINITY CHANGES IN THE DEEP WATERS OF THE WESTERN NORTH ATLANTIC

J. R. Barrett

The 4° isotherm dips from a depth of 1000 m on the north (Slope Water) side of the Gulf Stream to around 1700 m on the south (Sargasso Sea) side. An analysis of hydrographic station data in the northwestern portion of the basin indicates that there has been a decrease of salinity since 1960 at all temperature levels below this isotherm. The decrease is particularly noticeable north of 36°N and in the potential temperature range of 3.5° - 4.0°C, but significant decreases of salinity have also been found in the vicinity of Cape Hatteras and at deeper levels, even including the deepest water in the basin. The magnitude of the change in the temperature range 3.5° - 4.0° is 0.01‰ (Fig. 1); changes in the deeper waters of the basin range downwards to about 0.003‰ for the interval colder than 2.0°θ.

No significant changes of salinity were detected--using only Institution data--in the Bermuda area, but a time series analysis of the bi-monthly hydrographic data from the Bermuda Biological Station shows a steady increase of salinity at all levels below the 4° isotherm since 1959. The total increase since that year (when conductivity measurements were begun) is about 0.015‰. These were the only data suitable for a time series analysis. For the rest of the basin the data were divided into two periods: 1955-1960 and 1961-1967 on the basis of a preliminary inspection. It was thought that recognizable trends might emerge, as at Bermuda, but this did not occur.

No evidence to date indicates that either of these changes may be the result of a systematic error in sampling or measurement of salinity.

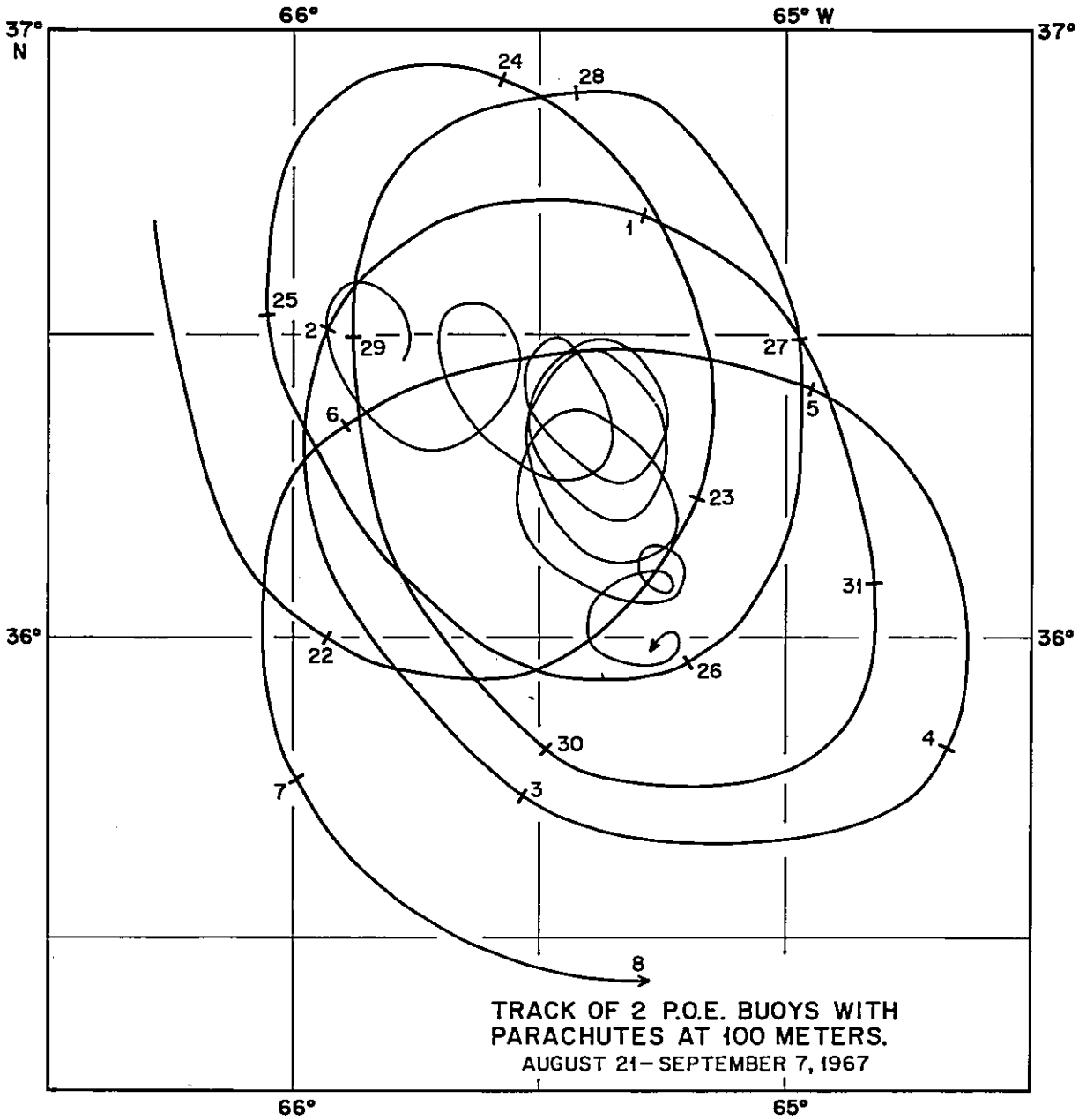

Fig. 1. (Fuglister, Parker and Stalcup) Track of two plank-on-edge buoys with parachutes at 100 meters, August 21-September 7, 1967.

POTENTIAL TEMP. 3.51 - 4.00

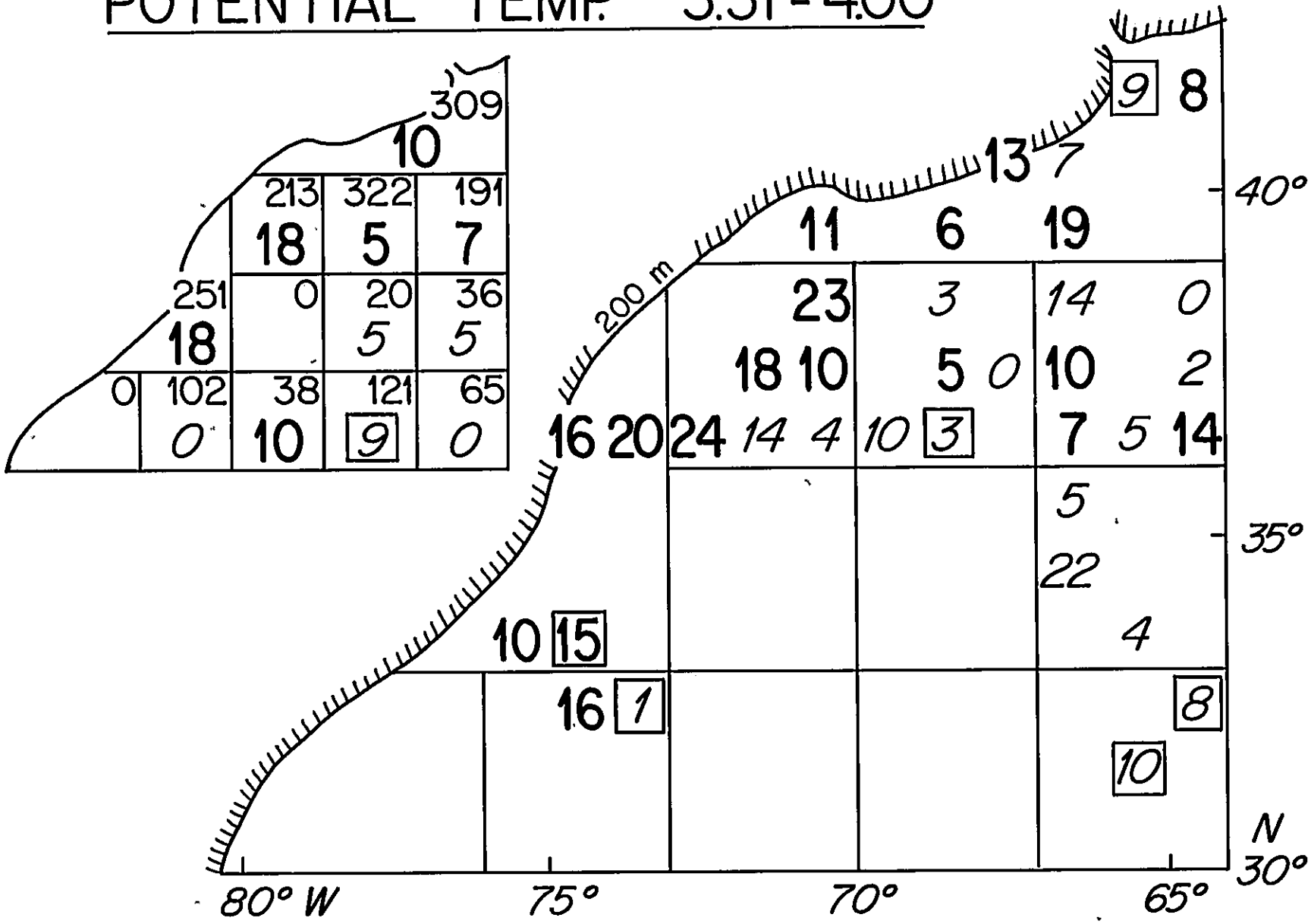

Fig. 1. (Barrett) Changes in salinity in the western Atlantic between 1955-60 and 1961-67. Numbers represent the mean differences in 0.001‰ (thousandths of a part per thousand) of salinity. An increase in salinity is represented by a boxed figure; others indicate a decrease. Heavy type indicates the mean difference was significant (t-test) at the 95% confidence level. Light type indicates the difference did not test as significant. Superscripts give the number of observations.

In the case of the freshening of the Slope Water it is hypothesized that this is a response either to the observed cooling trend which began in the Arctic (and world-wide) about 1950 (Mitchell, 1963), or possibly to the unusually severe winter of 1956-7 recorded at Ocean Weather Station "Bravo", in the central Labrador Sea which is the source area of the Sub-Arctic Intermediate Water. This water type (T = 3.5°C, S = 34.88‰ roughly) can be traced as a core of low salinity around the tail of the Grand Banks and westward into the Slope Water region at least as far as Cape Hatteras. The change in salinity in the temperature range of Fig. 1 is almost certainly the result of an increased supply of water from this source. The observed freshening of the deeper waters can also be traced to northern sources (Worthington and Wright, in preparation), except for that which occurs in the very deepest portion of the basin: below 2.0°θ. Water at this level is derived from the Antarctic and the observed freshening at this level remains unaccounted for in view of the great distance to the source region.

The increase of salinity at Bermuda is not necessarily the result of an increased outflow from the Mediterranean. The core of this high salinity feature lies somewhat to the south of Bermuda (Wüst and Defant, 1936) and the increase in salinity observed might merely be the result of a northward shift of this core. A horizontal displacement of about 200 miles would be required to account for the observed change.

The combined dynamic effect of the reduction of salinity in the Slope Water and the increase at Bermuda would be to reduce the net eastward flow of the Gulf Stream System to the north of Bermuda by about 10%. The reduction might be accomplished by increasing the westward flow north of Bermuda without changing the eastward transport of the Gulf Stream at all. This implies a flattening of the gyre such as would probably accompany a northward shift of the high salinity core. It is not at present clear how these changes in the distribution of properties and implied changes in circulation in the vicinity of Bermuda are related to the climatic fluctuation--if indeed they are.

The tide gauge records at Bermuda were examined to see if they showed any long period trends. Schroeder and Stommel (in press) have shown that fluctuations of tidal height there are closely related to changes in steric level. Thus, it was thought that a reduction of steric level due to the increase of salinity of the deep water might be reflected in the tide records over a long period. The sought for change would have been of the order of 2 cm at most, so it was surprising that the year-long tidal averages (with barometric effects removed) showed changes of the order of 10 cm. The average tidal height rose about that much from 1945 to 1959 or 1960 and then fell by about 5 cm to 1966. There was a great deal of "noise", but the suggestion is that changes in the water column above 4° have been (and are) occurring and that these may be related to the climatic fluctuation.

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TRANSPACIFIC HYDROGRAPHIC SECTIONS

Bruce A. Warren

As a joint project among the Scripps Institution of Oceanography, Massachusetts Institute of Technology, University of Hawaii, and Woods Hole Oceanographic Institution, two hydrographic sections were run across the South Pacific on Cruises 28 and 29 of the USNS *Eltanin,* research vessel for the U.S. Antarctic Research Program. Measured properties included temperature, salinity, oxygen, phosphate, silicate, nitrate and nitrite. Stations were not more than 100 miles apart, and much closer together in areas of particular interest such as continental slopes, basins, etc. At all stations observations were made from the surface to the ocean bottom.

The *Eltanin* departed Melbourne on 10 March 1967 and proceeded eastward along 43°S, arriving at the Chile coast on 10 May. Seventy-eight stations were occupied, along a section of length 11,200 km. After making a

supplementary section of seven stations across the Peru Current, the ship put in to Valparaiso on 18 May. She left Chile on 2 June, proceeded westward on 28°S, and reached Brisbane on 2 August. One hundred additional stations were made, the section on 28°S measuring 13,250 km in length.

MARINE PHYSICAL GEODESY AND ASTRONOMY

W. S. VonArx

If all the forces acting on the World Ocean were removed except for gravity, and the waters of the sea given time to stratify so that density became a function of pressure alone, the sea would be level. This level surface, the geoid, is a surface of constant gravity potential. The Marine Physical Geodesy Program has as its objectives, (a) to define the geoid at sea, and (b) to observe the departures of the physical sea surface from the geoid. Interpretation of such departures could, in turn, serve as a measure of the external forces acting upon the ocean and its responses to them.

The purpose of developing GEON as a method of navigation at sea has been two fold; first, to find astronomical ship's position by projecting local gravity-vertical against the stars, *(Sky and Telescope* 29 (6) 340-345, 1965) and second, to refine this capability to the point where differences between astronomical and geographic position can be observed at sea. From these differences, (the deflections of vertical) it is possible to define the departures of a level (equipotential) surface from the geographic spheroid and thus to establish a reference surface against which to study ocean tides, changes in sea level, set-up by wind stress, and if suitably refined, an origin for measuring the horizontal pressure gradients (and geostrophic flow) in ocean currents (*Limnology and Oceanography*, 10 (Suppl.): 1965-R265-R273).

The first successful measurements of deflections of vertical were made during the spring of 1966 from *Chain* working across the Puerto Rico Trench (*Science*, 1966 154, (3757): 1651-1654). While these results are crude by ordinary geodetic standards, they represent a long step toward the practice of physical geodesy at sea and the establishment of a fundamental datum for physical oceanographic measurements.

These early results have been compared with the deflections of vertical computed from the measured free-air gravity anomaly along the same traverse. While the computation of deflections of vertical from gravity leads to a subdued replica of the direct astrogeodetic measurements, gravity can be measured under cloudy skies. It, therefore, seems desirable to use both methods insofar as possible. Gravimetric observations are being made with a Vibrating String Accelerometer supported on a Mark 19 Meridian Gyrocompass as a stable table.

The Mark 19 Mod. 3C meridian-gyrocompass is also used as the vertical sensor in the Geon System. To be useful in these services a vertical must be sensed to 5 arc seconds which is ordinarily beyond the capability of the Mark 19 system. With the help of the engineering staff of the Marine Systems Division, Sperry Rand Corporation, the Mark 19 vertical reference has been greatly improved by adding angular accelerometers to detect ship motion. These accelerometers produce velocity and acceleration signals to be added to the displacement signals entering the follow-up amplifier system. With careful adjustment of displacement, velocity and acceleration signals the servo systems can now drive the phantom to keep in close step with the indicated vertical from the gyros themselves. This improvement has made possible the recent measurements of sea surface tilt and has also improved the ease and accuracy of astronomical navigation very considerably. Under good conditions astronomical position can now be found to 0.1 arc minute which is equivalent in accuracy to satellite navigation reduced to the ellipsoid.

In preparation for measurements of the tilt of the horizon studies have been made of the optical noise in light propagated at near-grazing incidence across water surfaces. The images of stars at low altitude have been observed in time series to measure the power spectra of their image motions and point spreading functions. It turns out that with a sufficiently long time series (obtained with a movie camera running at 8 frames per second) the low frequency image displacement errors can be simply steered out and that the high frequency errors of point spreading may be averaged to zero by integration of a statistically significant number of time-variant samples. Proof of this hypothesis has been obtained in images on photographic printing paper built up from 1, 12, 50 and 250 separate exposures of the planet Saturn. Real-time image processing by these methods may permit the horizon image to be examined not only with atmospheric disturbances largely eliminated but also corrected for ship heave and wave motion to a point where meaningful measurements of sea surface tilt may be made at sea.

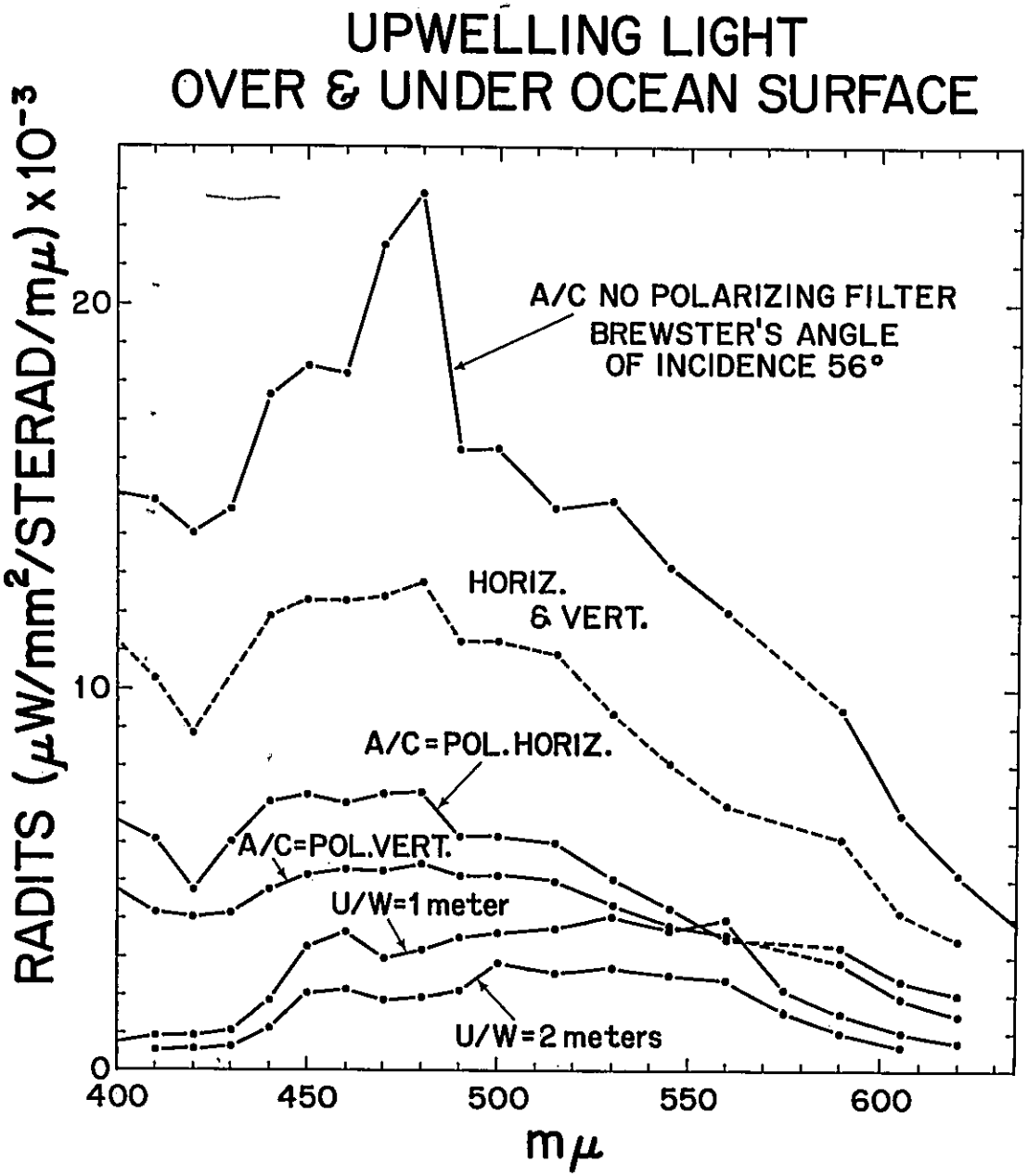


Fig. 1. (Clarke, Ewing, Conrad, Alexander and Mayer) Underwater measurements were made at one and two meters synchronously with airborne measurements filtered through a polarizing screen to discriminate against sky reflection.

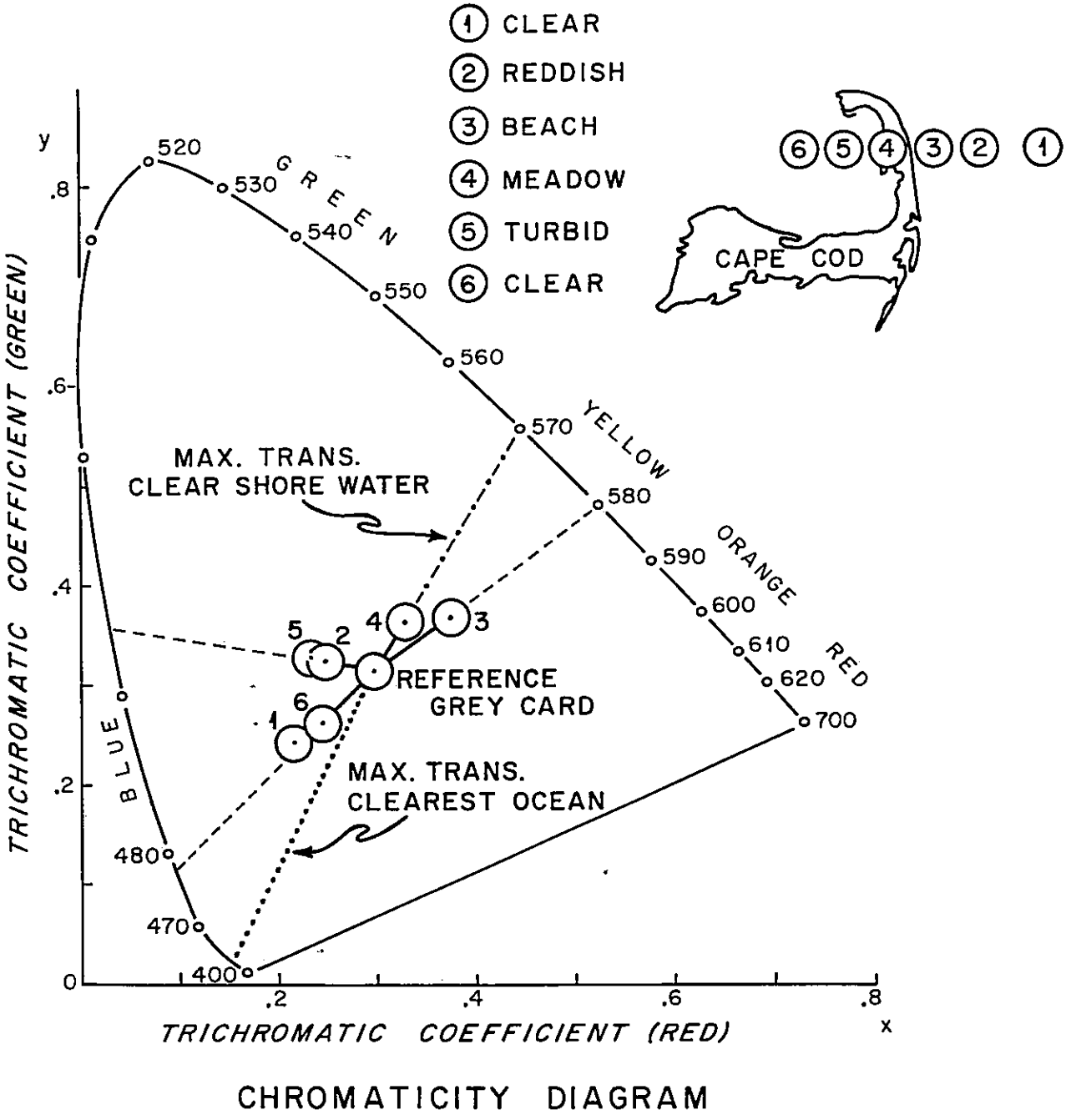


Fig. 2. (Clarke, Ewing, Conrad, Alexander and Mayer) Colorimetric analysis of a series of spectra of the ocean taken from the aircraft at the location shown on the inset.

AERO-SPACE OCEANOGRAPHY

Gifford C. Ewing

During the summer of 1967, the National Academy of Science National Research Council conducted a study of space applications to earth resources. The chairman of the subpanel on Oceanography was Gifford C. Ewing of the Woods Hole Oceanographic Institution and numbered among its seven members Charles S. Yentsch also from the Institution.

The subpanel attempted to identify those physical parameters of the upper layers of the sea that are amenable to remote sensing from aircraft or satellites and to evaluate their relative importance to scientists, engineers and to the general public. These parameters, listed in decreasing order of priority are:

1. Sea-surface temperature by infrared and microwave radiometry and by radio telemetry,
2. Imagery by photography, imaging infrared thermal mapping and imaging radar,
3. Detection of sea color and chlorophyll by spectrogrammetry,
4. Dynamic topography of the sea surface by radar or laser altimetry,
5. Surface drift rates by tracking of floating objects such as transponding IRLS (Interrogation, Recording and Location Subsystem) buoys, and
6. Sea state by measurement of radar roughness scatter.

The aero-space program at the Woods Hole Oceanographic Institution is designed to implement those items in the list shown above which are most clearly within the Institution's present competence. All involve the use of the C 54 Q aircraft. During 1967 projects 1, 3 and 5 were initiated. Results to date are as follows:

Sea surface temperature by improved radiometry has been carried on at the Institution since 1952. The current scientific application to the problem of Gulf Stream eddies is reported elsewhere.

SEA-SURFACE SPECTROGRAMMETRY

George L. Clarke, Gifford C. Ewing, A. Conrad, R. M. Alexander and Gary Mayer

Sea surface color measurements were made using a pair of 28-channel spectrophotometers loaned by the Massachusetts Institute of Technology Experimental Astronomy Laboratory. While one of the photometers was flown at 1000 feet over the *Crawford*, and the other was used under water from shipboard to measure the upward scattered light from beneath the sea surface at varying depths. A comparison of the results is shown in Fig. 1 where the underwater measurements were made at 1 and 2 meters synchronously with airborne measurements filtered through a polarizing screen to discriminate against sky reflection. The spectra agree fairly well at the red end of the scale but diverge considerably at the blue end, regardless of the orientation of the polarizing filter. Maximum light is transmitted in the region of the blue-green as would be expected due to the optical characteristics of the average coastal waters.

Figure 2 shows a colormetric analysis of a series of spectra of the ocean taken from the aircraft at the location shown on the annexed chart. The diagram illustrates how the dominant wavelength shifts from blue green toward the green and into the yellow as the shore is approached and how the excitation purity or color saturation is decreased in shallower water. In general it is to be expected that light upwelling from shallow layers (either because of reflection from the bottom or from scatterers in the sea) is less colored by spectral absorptions than that from deeper reflection. The overall reflectance or brightness is also increased by shallow reflections.

It is anticipated that spectral analysis of upwelling light from the sea may serve to discriminate between water masses and to locate areas of high sediment load or biological activity. In some cases, as at the inshore edge of the Gulf Stream, the color contrasts are so strong as to be readily observed by naked eye or by simple color photography. It is hoped to develop sensitive methods of photometry that will reveal much more subtle variations of color hue, saturation and underwater reflectance. Such methods if successful from low-flying aircraft give promise of utility in reconnaissance of the world oceans from satellites.

SURFACE DRIFT RATES BY IRLS SATELLITE TRANSPONDERS

Foster L. Striffler, Edward A. Denton and Ferdinand C. Scagleone

The portion of the year 1967 from March through December was spent in the redesigning and construction of the digital-processing portion of the IRLS/NIMBUS (Interrogation, Recording and Location Subsystem) experiment.

The IRLS system is a location, and data link package which will be on board the NIMBUS B satellite to be launched in April or May of 1968. Briefly, the operation is as follows: The satellite will be programmed to interrogate the various buoys and land stations that it will see in a particular orbit (each buoy or station has its now particular digital address). When a buoy hears its own address, it will turn itself on and transmit to the satellite the oceanographic data it is collecting at that time and also the satellite will locate the buoy by measuring the time delay of the satellite-to-buoy-to-satellite transmission. The satellite will store the oceanographic and time-delay data in its core memory and this data in turn will be relayed to the ground-control station in Alaska.

The logic design for the buoy electronics had been done by Radiation Inc. of Melbourne, Florida, but they had used special Texas Instruments integrated circuits which were needlessly expensive, and, in fact, they are no longer produced by that firm. It was then decided to use Motorola integrated circuits and, therefore, the logic diagrams were redesigned for these devices. The digital-processing portion of the IRLS Buoy consists of a 100 Kc. phase synchronizer circuit, the buoy address recognizer, the data "formatter" and the analogue-to-digital converter. In addition to the digital portion, the receiver/transmitter package was purchased from TFR Inc. of Springfield, Virginia. The Archimedean spiral antenna and the thermistor chain are being built in the instrument shop at the Woods Hole Oceanographic Institution. Also, the following miscellaneous items are being designed and constructed at the Institution: the buoy, the battery package, D.C. - to D. C.-converter and the antenna-support structure. These buoys (three planned for 1968) will be used to investigate the flow of the Gulf Stream, in particular the eddies which occasionally break off from the Gulf Stream, and in collaboration with Dean F. Bumpus, to track the surface drift on Georges Bank during those seasons when the recovery of drift bottles has been meagre.

INFRARED AND SHORT-WAVE RADIATION STUDIES

Peter M. Saunders

Work has continued on the topic of radiation thermometry. The objective has been to improve the accuracy of remote measurements of the surface temperature of the ocean. The influence of surface roughness on measurements made with a radiation thermometer has been determined theoretically and shown to be very small except for oblique viewing; this conclusion has been verified by experiment. A theoretical study has also been made of the manner in which the temperature of the ocean skin is linked with the interior or bulk water value; differences are predicted to be only a few tenths of a degree C though this hypothesis remains untested so far. When estimates of the surface temperature of the ocean are made from great heights within the atmosphere (or from outside it) a careful evaluation must be made of atmospheric absorption and emission. Such observations are generally attempted in wavelength regions of minimum absorption (windows), whose properties are still imperfectly understood. Current research includes investigation of the 8-12 micron window, through which most radiation thermometry measurements are made.

In a related field, studies of the optical properties of a roughened surface have given insight into the nature of the ocean horizon and resulted in the first quantitative explanation of this phenomenon. In this connection, it should be remembered that a calm ocean has no horizon; sea and sky blend there with equal color and brightness.

With the assistance of Mr. Richard Payne, a graduate student from University of Rhode Island, a program of systematic measurement of the incoming and outgoing short-wave radiation in the marine environment has been initiated. Special emphasis is to be placed on testing climatological estimates of these quantities.

NORTHERN CRUISE ABOARD C.S.S. *HUDSON*

L. V. Worthington

During the period January to April 1967 a joint cruise to northern waters was undertaken by the Bedford Institute of Oceanography and this Institution. The purpose of this cruise, under the leadership of C. R. Mann of the Bedford Institute, was to gain further knowledge of the volume transport of the Norwegian Sea overflows into the North Atlantic.

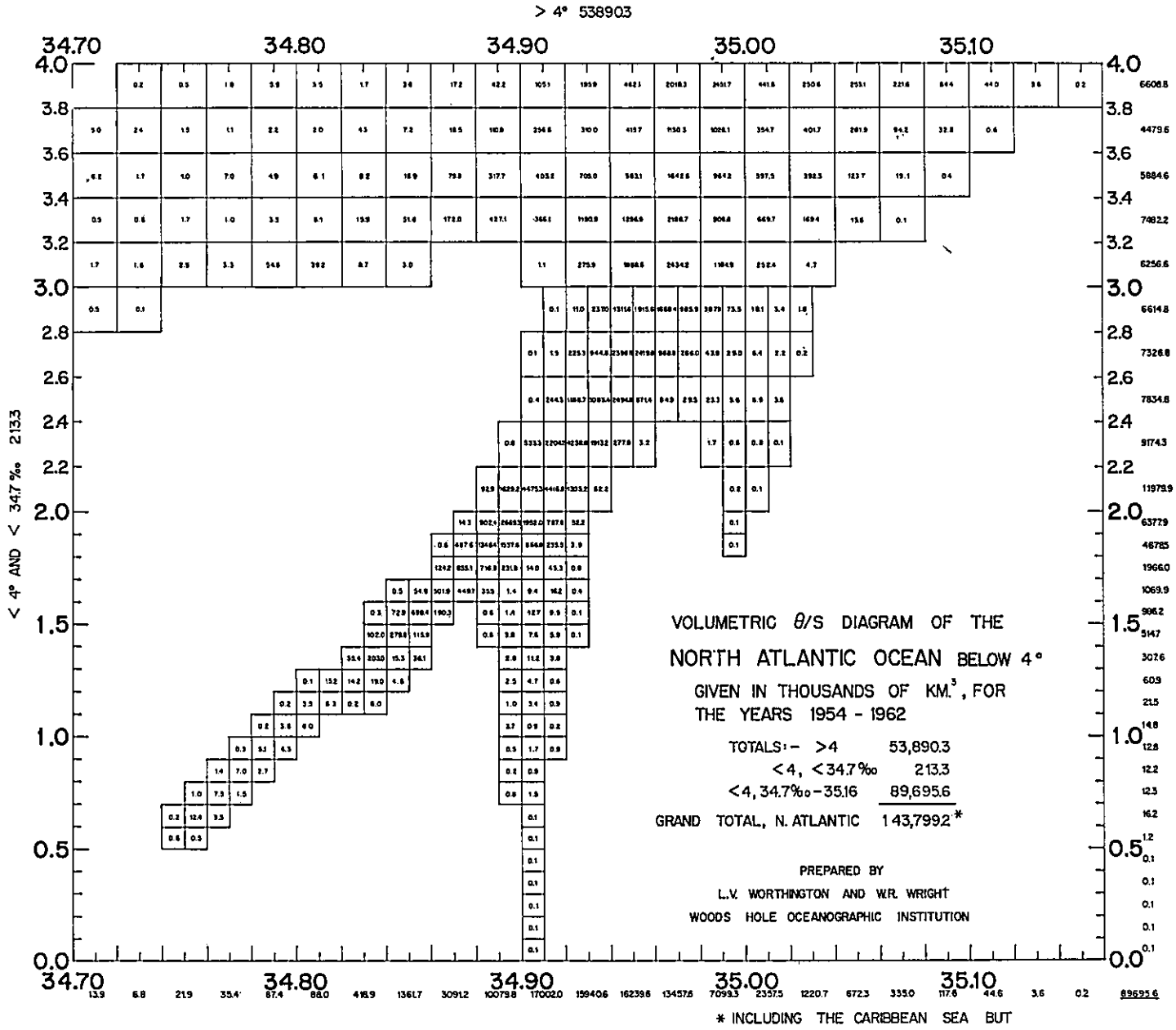


Fig. 1. (Worthington and Wright) Volumetric θ/S diagram of the North Atlantic Ocean below 4°C given in thousands of km^3 for the years 1954-1962 including the Caribbean Sea, but excluding other adjacent seas.

There are two of these overflows--one through the Denmark Strait between Greenland and Iceland and the other between Iceland and Faroe Bank. These overflows constitute the major northern source of deep water for the world oceans. The latter overflow is the better known--Norwegian Sea water from this source can be traced from south of Iceland along the eastern slope of the Reykjanes Ridge to the Faraday Hills where it passes through a gap in the ridge and flows northward along the western slope of the Reykjanes Ridge. Its transport has been estimated at 5 million m^3/sec.

The transport of the Denmark Strait overflow is less well known since no direct current measurements have been made close to its source. The cruise was planned to give major attention to this overflow. In January an array of 30 current meters was anchored in the Denmark Strait. Subsequently, a detailed oceanographic survey was made of the Irminger Sea and Swallow-float measurements were made on both sides of the Reykjanes Ridge to check on the transport of the other overflow.

Unhappily we must report almost complete failure in the case of the Denmark Strait overflow. Of six moorings anchored only two were recovered, neither of these from the Greenland continental slope where the cold water is found and the currents should be strongest. Of the ten current meters recovered in these moorings only two gave useful records. It seems most likely that the overflow currents in the Denmark Strait are too strong to be measured with the present system of moorings. The two current meters which worked show very interesting results: one of these was periodically in the overflow water and measured southwestward velocities of as high as 144 cm/sec. The other was to the westward of the overflow but it showed that there is a consistent northwestward flow of Atlantic water being entrained into the overflow.

The remaining work in this cruise was successfully accomplished; the Swallow-float measurements on either side of the Reykjanes Ridge showed that the Iceland-Faroe Bank overflow water was still flowing southward east of the ridge and northward west of the ridge. Precise computations of the volume transport have not been completed but the current appears to have been weaker than usual, particularly on the eastern slope of the ridge.

VOLUMETRIC θ/S DIAGRAM FOR NORTH ATLANTIC

L. V. Worthington and W. R. Wright

A fine scale volumetric θ/S diagram (Fig. 1) has been prepared for the North Atlantic Ocean. This diagram is based on data taken during an eight-year period centered on the International Geophysical Year, principally by the staff of this Institution. At present the North Atlantic, which contains only 11% of the water of the World oceans by volume, is the only ocean which has been adequately surveyed with a sufficient number of deep stations and with precise temperature and salinity measurements.

It is hoped that this diagram will be useful in the study of long-scale climatic fluctuations since it shows us the exact distribution and quantity of different water masses as they existed during this period. Any changes which take place in the future, however small, will be easy to detect.

For example, the Antarctic Bottom Water in the North Atlantic which can be seen on the diagram between 1.8° - 34.89‰ and 0.5° - 34.74‰ consisted of 4.8 million km^3. Any increase in the supply of this water will presumably enlarge this volume. Similarly, the water on the diagram between 1.8° and 0.0° at a salinity of about 34.90‰ was exclusively supplied by the Denmark Strait overflow, and the water below 2.8° but more saline than 34.98‰ was exclusively supplied by the Iceland-Faroes overflow.

The great bulk of the deep water in the North Atlantic fell along a line from 4° - 35.00‰, 3° - 34.96‰ and 2° - 34.90‰. The squares close to this line contain 90% of this water. At the time of the observations most of this water could be traced to the Denmark Strait overflow which appeared to be the most active contributor. However, it is not yet clear how steady the production of deep water is from any source.

TEMPERATURE STRUCTURE

Elizabeth H. Schroeder

A proposed atlas of the average temperature of the North Atlantic at six discrete depths continues to be of prime interest. As plotting of the basic charts was resumed after new data from various sources were added, it was

discovered that, because of the computer program written and used at the Scripps Institution of Oceanography, the temperature-depth structure in areas of currents and adjoining water masses and in places of shallow and varying depths was being distorted. As a remedy for this, the temperature-depth structure is being reconstructed subjectively. This is being accomplished by taking each one-degree quadrangle in the critical areas and separating the water types so that all individual characteristics are not erased by the averaging and smoothing process of the program. This is a painstaking process and will undoubtedly take a considerable length of time. It is felt that the results of this effort and the computer smoothed temperatures in mid-ocean, when combined, will result in a useful and informative atlas for use for prediction purposes, among others. The atlas is to be published in color by NAVOCEANO and will be one of several which will include the Pacific and Indian oceans presently being done by Margaret K. Robinson of the Scripps Institution of Oceanography.

PANULIRUS DATA

Elizabeth H. Schroeder

Since June 1954, following a program conceived at the Woods Hole Oceanographic Institution, 283 hydrographic stations have been made by personnel of the Bermuda Biological Station aboard the *Panulirus*. In 1967, from January through the middle of October, eighteen stations have been made. These stations have been corrected and handled in the usual manner which includes basic analysis of temperature, salinity, sigma-t, and oxygen.

Currently, this continuing series of stations is being subjected to analysis to determine if the slight increase in the salinity of the colder water below the thermocline during the past few years is real, is due to a faulty sampling technique, or is dependent on the particular salinometer used for determinations. On request, the Bermuda Biological Station has sent water samples to be analyzed by Joseph Barrett of the Woods Hole Oceanographic Institution. This duplicate analysis has shown that differences in the salinity readings do exist, but are not constant, so that further study of these data and other data taken in the same area must be undertaken in order to understand more completely the changes in the temperature-salinity relationship of this water over a period of time.

BATHYTHERMOGRAPH PROCESSING

Elizabeth H. Schroeder

During the past year, the increasing use of the expendable BT and the coding of temperatures and pertinent data for each slide processed by this section has necessitated some changes in what normally is rather routine work. Most of the processing can be expressed by simply stating numbers. 5,061 BT slides were received, 4,960 were photographed and the negatives read, and 17,704 ozalid prints were completed. There is always a small percentage of the slides which are not usable because they are too badly broken or because they have traces which are not made by any mechanical instrument. 6,961 negatives were coded for digitization, 1,696 expendable BT graphs were read, 10,046 BT prints received from NODC were checked for temperature corrections and read, 8,991 hydrographic stations were copied from various sources, and 19,667 BT cards, including expendable BT's and 8,947 stations were averaged at standard depths by one-degree quadrangles, and added to the data collection. In addition to this, 73 BT reading grids were made for instruments calibrated at the Institution. There is a constant quality check to ascertain that questionable data are not added to the collection and that any previous errors in the historical data are eliminated.

ATMOSPHERIC PHYSICS

Duncan C. Blanchard

Experimental studies on the generation of raindrop-size distributions were completed. In brief, it had been proposed that the exponential-type distributions found in heavy rain do not depend on the initial conditions in the cloud (as is commonly thought) but on subsequent raindrop collisions and breakup. Artificial raindrop distributions were generated by letting a continuous solid stream of water fall through the air. The stream broke into large drops which continued to interact and break during the available 70 meters of fall. Measurements of the drop spectra at the bottom of the "rain" column revealed that the small drops had an exponential distribution while the large drops did not. But

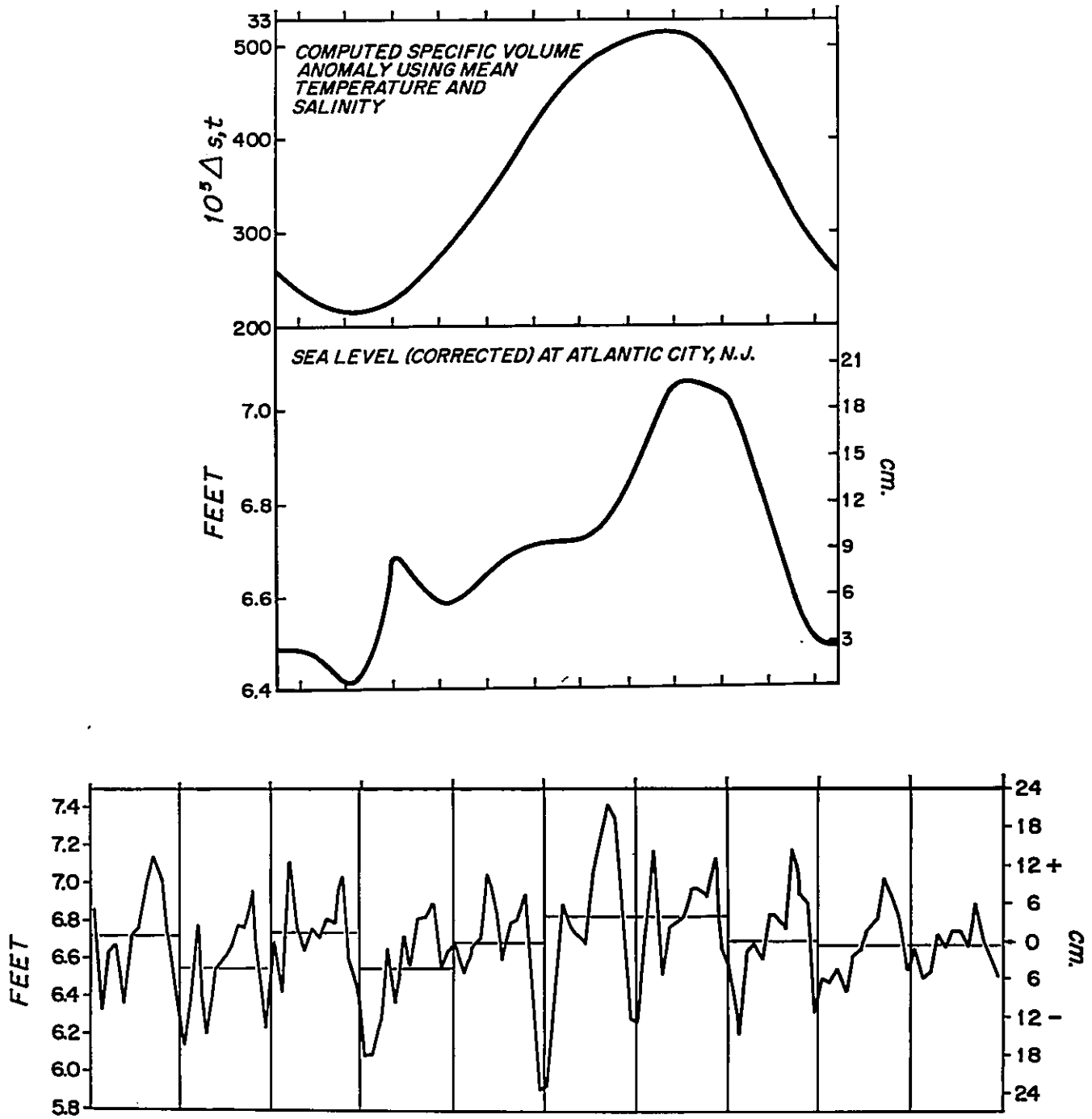


Fig. 1. (Bumpus) Mean annual cycle (uppermost curve) of the computed specific volume anomaly from temperature and salinity data from Five Fathom Bank Lightship, and the sea level (middle curve) at Atlantic City for the ten year period 1956-1965. The annual cycles of sea level (bottom curve) at Atlantic City for the ten year period 1956-1965.

calculation indicated that had another 200 meters of fall been available, the large drops would have broken and the entire distribution would have been similar to that found in heavy rain. The hypothesis, then, of drop breakup as the main factor in the generation of raindrop-size distributions is considered highly probable, but confirming experiments using over 200 meters of free fall need to be done.

A field trip to the island of Hawaii was carried out in the fall. We engaged in a number of cooperative projects with members of the Hawaiian Institute of Geophysics. Most of the work was done from atop a 75-foot tower erected along the windward shore of the island. At that height our aerosol and water vapor samples were not contaminated by spray from the local surf. Samples of sea-salt particles were obtained by exposing fine platinum wires to the air. The samples were analyzed both for the amount of surface active organic material and for sea-salt. It is suspected that organic material on the salt particles may be the source of the extraordinary amounts of iodine that other workers have found on the particles. A large quantity of organic material was found in the present work, and the day-to-day variations will be compared to those of the iodine (the iodine work was done simultaneously by members of the Hawaiian group).

Another of the more successful of the field trip projects was the measurement of the production of atmospheric condensation nuclei by the sea. The sea as a source of these nuclei has long been debated, but no direct data had ever been obtained. We believe we have obtained such data.

CIRCULATION ON THE CONTINENTAL SHELF

Dean F. Bumpus

The rationale for this research is to determine what the general circulation patterns are, which departures from the generalized system are seasonal and which are due to climatic or other changes in the environment.

Methods: In late 1955 the lightships along the east coast of the United States were equipped with simple tools for measuring temperature surface and bottom and for taking water samples at the surface and bottom which are analyzed here in the laboratory for salinity. Subsequently these lightships released drift bottles daily and various cooperating agencies employing ships and aircraft over the continental shelf have released drift bottles and sea-bed drifters, recently on a monthly basis. Studies on the runoff cycle and the circulation in the Middle Atlantic Bight area of the continental shelf, based chiefly on the river effluent, lightship salinity, and drift bottle data have been made and are continuing.

A particular investigation was carried out regarding a reversal in the normally southerly residual drift off the coasts of New Jersey, Delaware, Maryland and Virginia, especially during July and August during the recent drought (1962-1965) in which we considered the effect of the drought in the steric sea level.

Figure 1 (upper curve) represents the specific volume anomaly calculated from the means of the surface and bottom temperatures and salinities at Five Fathom Lightship. Its minimum is in January coincident with the minimum of temperature and maximum salinity. Its maximum in September lies between the time of maximum surface temperature and maximum bottom temperature and 4 months later than the surface salinity minimum. The monthly mean sea level at Atlantic City corrected to the mean atmospheric pressure is also shown in Fig. I (middle curve). Except for the large hump in March there is a plausible relationship, as would be expected, between the sea level curve and the specific volume anomaly.

Inasmuch as the range in sea level is approximately the same in deep water as it is at Atlantic City and the annual oscillation is in phase, a modification in the steric anomaly at the coast of as much as 5 cm can reduce a 2 mile per day southerly drift to nil and permit the prevailing southwesterly winds to have a reversing effect on the flow. Certainly the effect of changes in the river effluent are most effective on the steric anomaly next to the coast. Hence a paucity of runoff will cause a reduction in steric sea level at the shoreward edge of the shelf. Such appears to have been the case during the recent dought (Fig. 1, lower curve).

On the basis of the runoff and salinities at the light stations we would have predicted a reversal in the drift in mid-summer of 1966, but normal southerly flow duirng 1967. Reversals were common in mid-summer of 1966 and rare indeed (chiefly under Cape Charles and Cape May) in 1967. The southerly drift was well developed and fast, 5-10 miles per day, this year with occasional bursts past Cape Hatteras into the Carolinian provinces. We anticipate another look at Atlantic City sea level data early in 1968 to see if the expected relationships between river effluent, shelf water salinities and sea level exist.

OCEANOGRAPHIC OBSERVATION POSTS

Joseph Chase

The Oceanographic Observation Post study was begun in late 1955. The data consist of temperatures and salinities from lightships, light stations and shore locations along the east coast of the United States. The analyses of the data for each year are published by the Fish and Wildlife Service of the U. S. Department of the Interior in the *Special Scientific Report* series and latterly in the *Data Report* series.

At present the report for the year 1965 is near completion and those for 1966 and 1967 are in the processing stage.

In 1965 the minimum 10-day average temperatures occurred in February at the northern observation posts whereas at the remaining posts there was a tendency toward double minima with the lowest 10-day means occurring randomly in January, February or March. All along the coast from Mt. Desert Rock (Maine) to Frying Pan Shoals (N.C.) there was usually good correspondence between air and water temperatures. The surface water temperatures at Diamond Shoal were far below normal in January, February and March. The vernal warming was steady in most areas and occurred earliest in the south. The maxima occurred in late July at Portland and Boston lightships, in September at Chesapeake Lightship and Light Station and at Diamond Shoal Lightship, and in August at the remaining offshore stations. At the more northerly stations the maxima were well marked in comparison with those of 1964. The correspondence with air temperature was generally good. The autumnal cooling was gradual at most observation posts and began earliest in the north.

LINE ISLANDS EXPERIMENT

Andrew F. Bunker

An intensive observational program was organized by meteorologists of the National Center for Atmospheric Research to study the structure of the intertropical convergence zone of the Pacific Ocean in the region of the Line Islands. For this study, several aircraft, one oceanographic ship, three island stations and a synchronous satellite were utilized during March, April and May, 1967. The Woods Hole Oceanographic Institution participated by flying the C-54Q aircraft to Christmas and Canton Islands to make observations of clouds, rain areas, temperatures, humidity, winds, turbulence, turbulent fluxes, and solar radiation. Sea surface temperatures were obtained by a group from Colorado State University with an infra-red radiometer which they mounted on our aircraft. The aircraft made a total of 12 observational flights in the area for a total of about 111 flying hours. Figure 1 shows the tracks flown by the aircraft out of Honolulu, Christmas and Canton Islands.

Although the task of processing the data is far from complete, preliminary inspection and analysis of the data show that we have gained new knowledge and insight into the structure and extent of the convergence zone and its relation to the clear equatorial zone to the south of it. Much of the credit for obtaining this new information must be given to the photographs of the clouds taken by the synchronous satellite sent up to a position over the equator at 150°W. Figure 2 shows four photographs taken by the satellite on May 3, 1967. The Institution's C-54 was flying through the long band of convergence zone clouds shown in the center of the top photographs while these pictures were being taken. When the wind, temperature and turbulence data taken by the aircraft are analyzed in conjunction with these photographs our knowledge of this feature of the tropical atmosphere will be greatly increased.

INDIAN OCEAN METEOROLOGY

Andrew F. Bunker, Margaret Chaffee, F. Claude Ronne

Work has continued on the analysis of the meteorological data obtained during the International Indian Ocean Expedition. The monograph on Indian Ocean clouds is nearly complete, and should be in its final form and sent to the publishers early in 1968.

Analyses of turbulence over the Indian Ocean and its relation to the thermal structure of the atmosphere have been made, but are not yet complete. It is of interest that the evaporation of water vapor from the sea determined from the aircraft turbulent flux system gave values that are 75% of the values determined by University of Washington meteorologists from the profile and the integral methods.

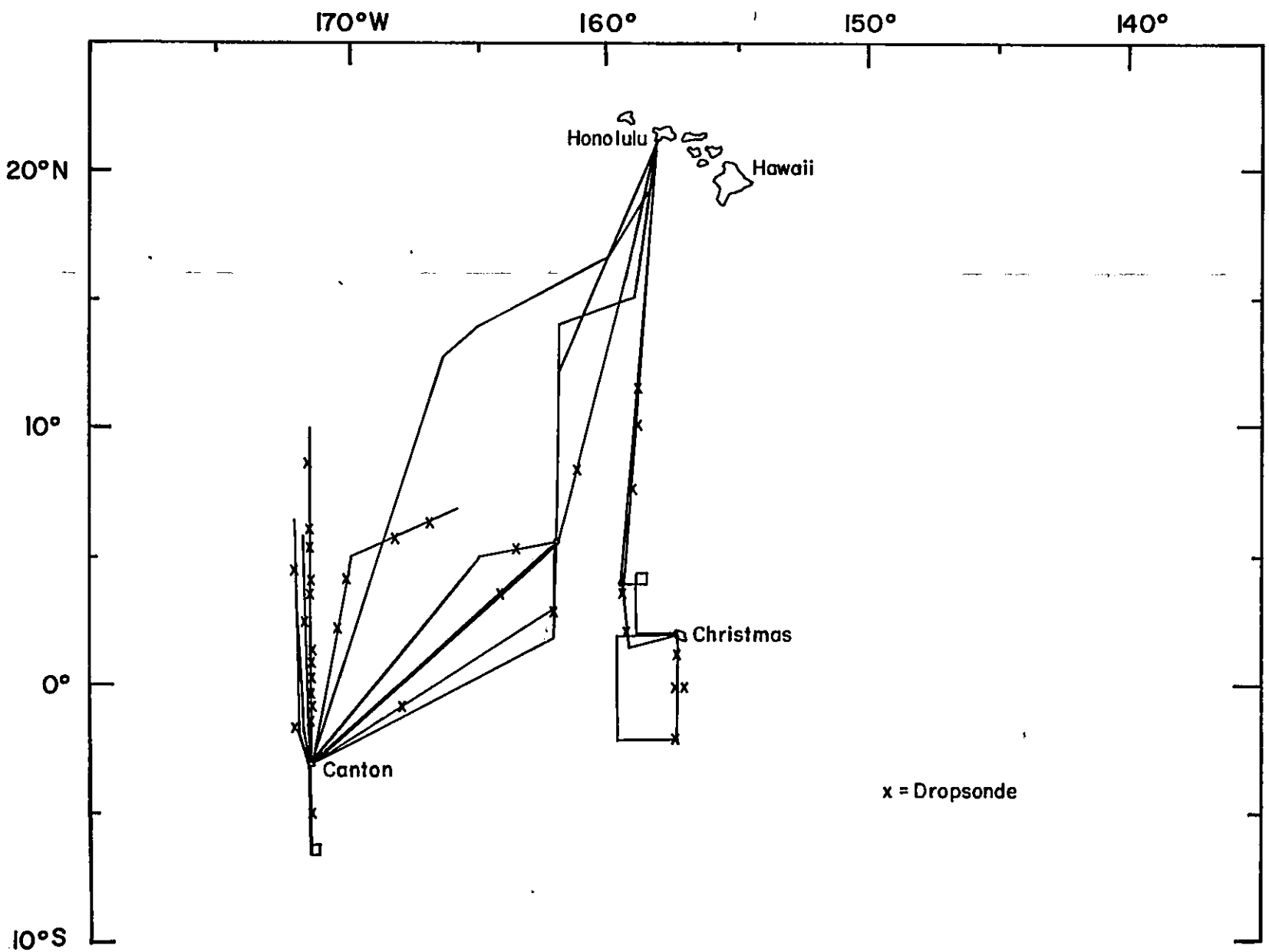
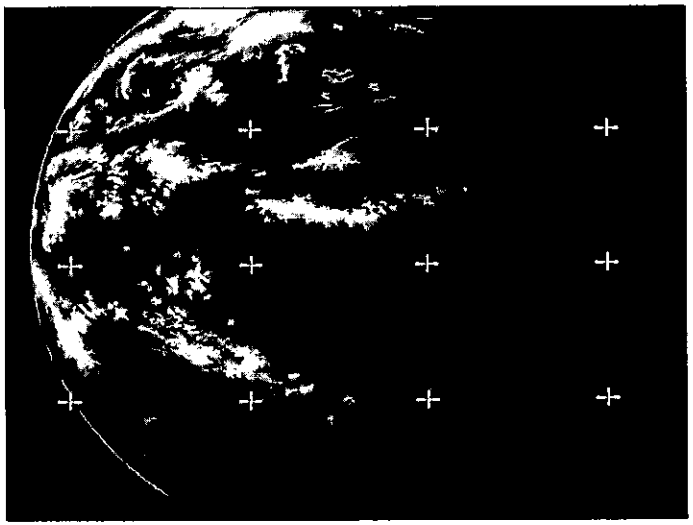


Fig. 1. (Bunker) Track chart flown by aircraft out of Honolulu, Christmas and Canton Islands.



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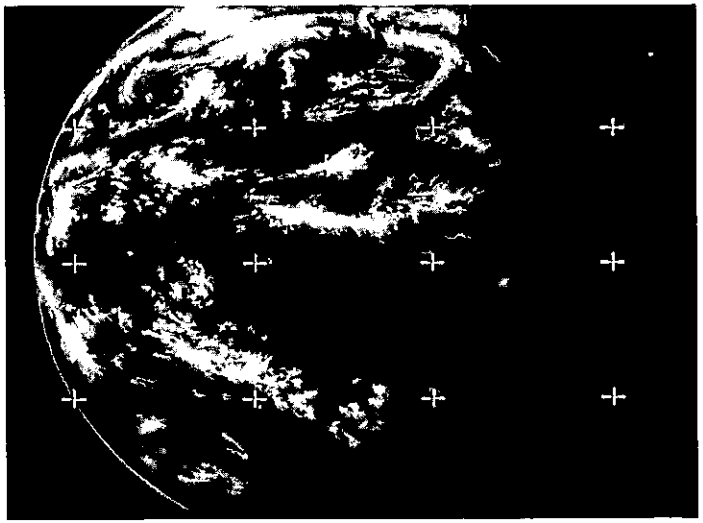

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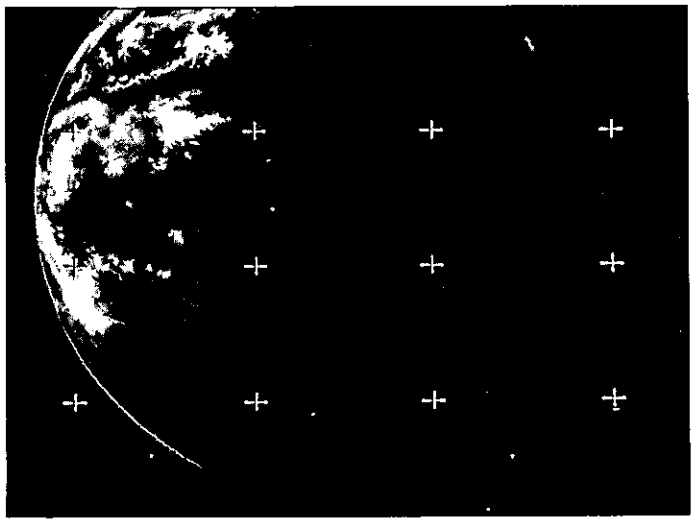

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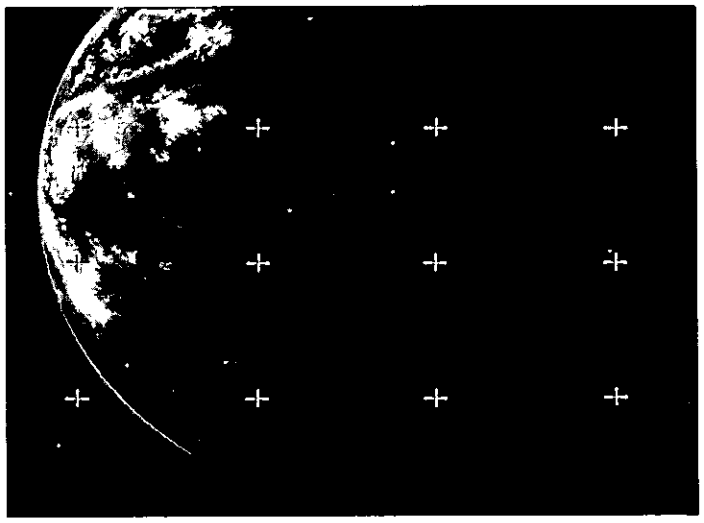

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Fig. 2. (Bunker) Photographs from satellite.

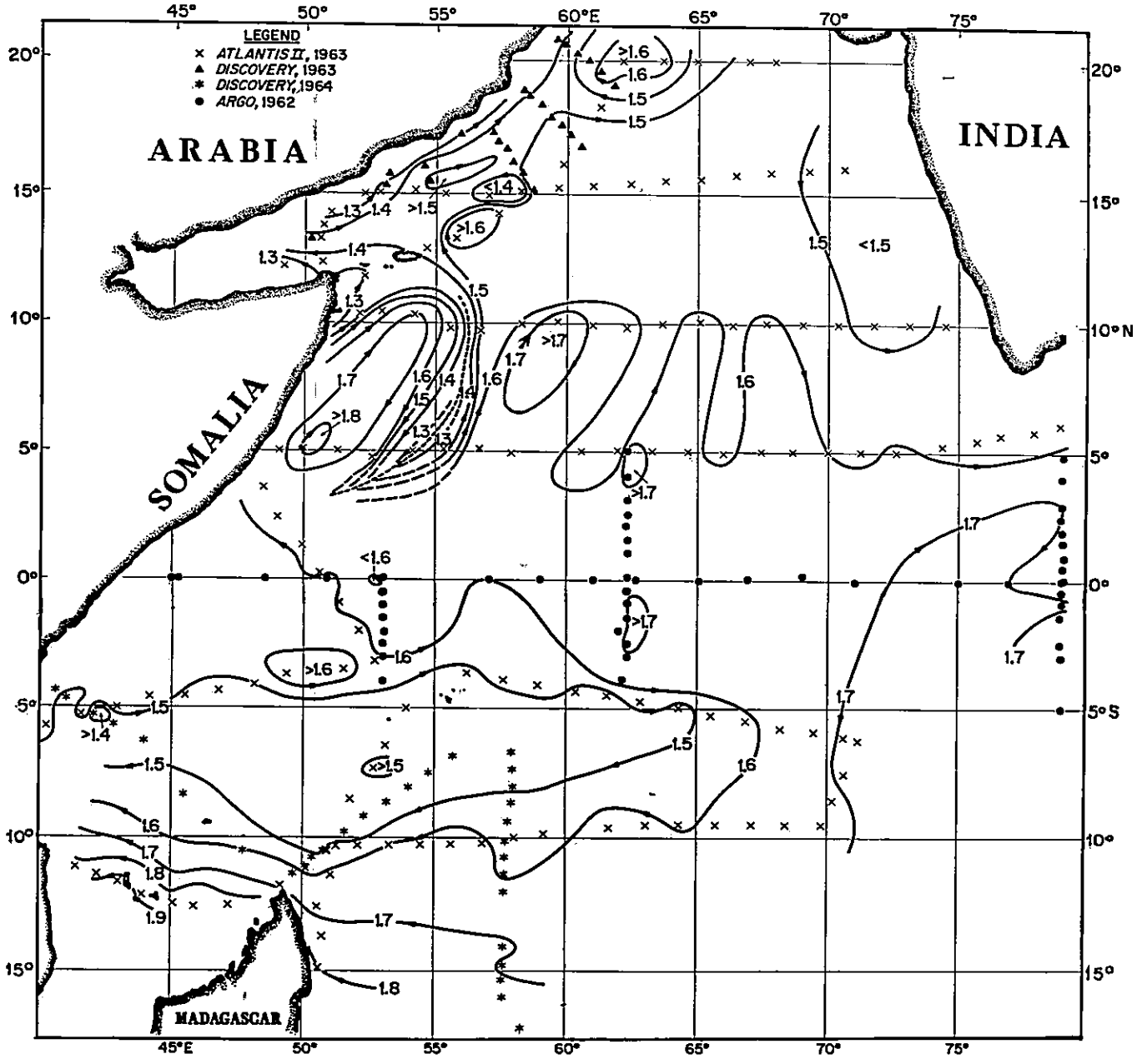

Fig. 1. (Bruce) Geopotential topography of the sea surface relative to 1000-decibars in the western Indian Ocean during northern summer (southwest monsoon). Units are in dynamic meters; contour intervals are 0.1 dy m. Short-dashed line along eastern edge of Somali anticyclonic circulation is estimated position of cold boundary from BT stations. Long-dashed lines in same area are estimation of convergence of contours with cold boundary.

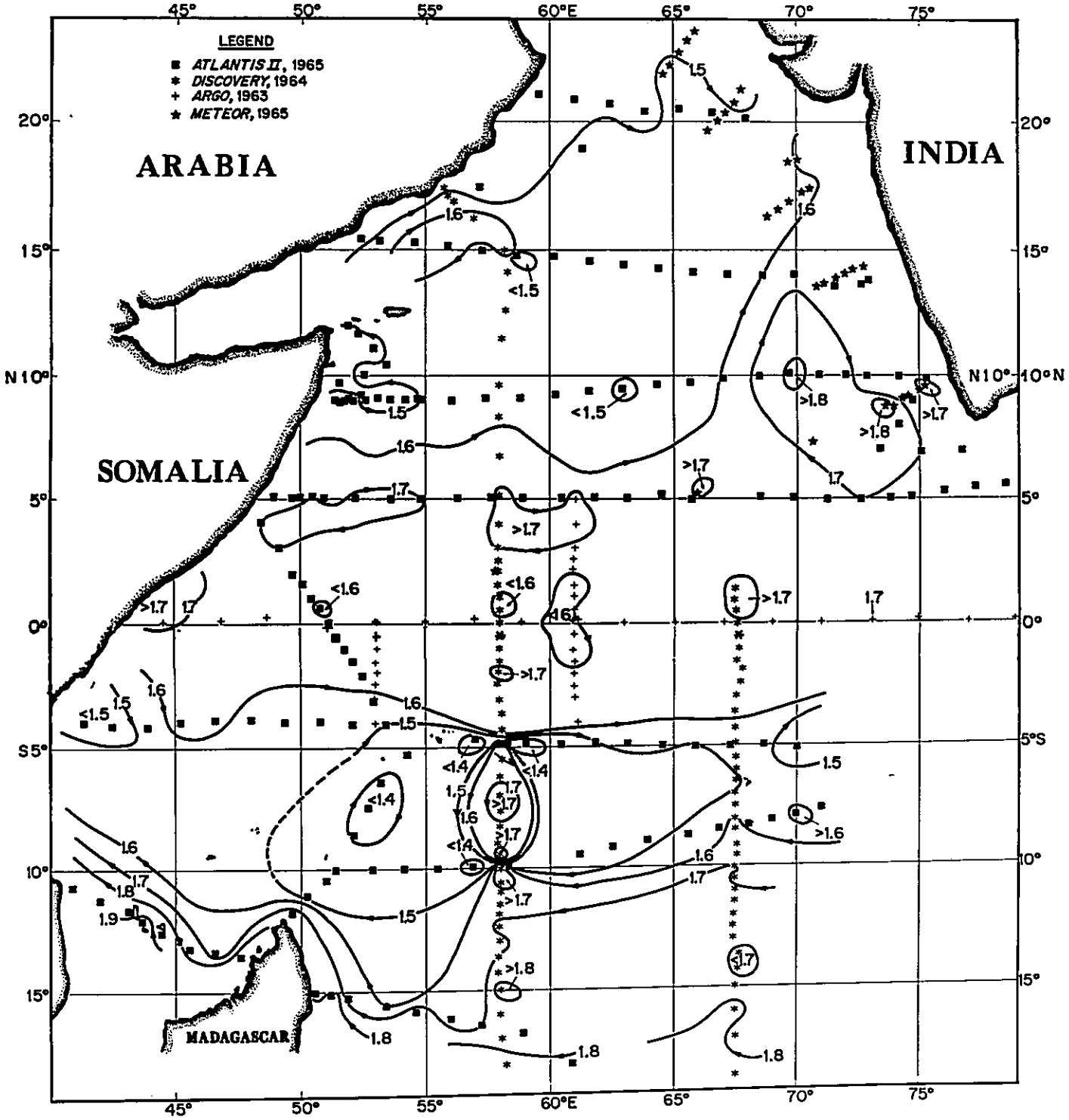

Fig. 2. (Bruce) Geopotential topography of the sea surface relative to 1000-decibars in the western Indian Ocean during the northern winter (northeast monsoon). Units are in dynamic meters; contour intervals are 0.1 dy m.

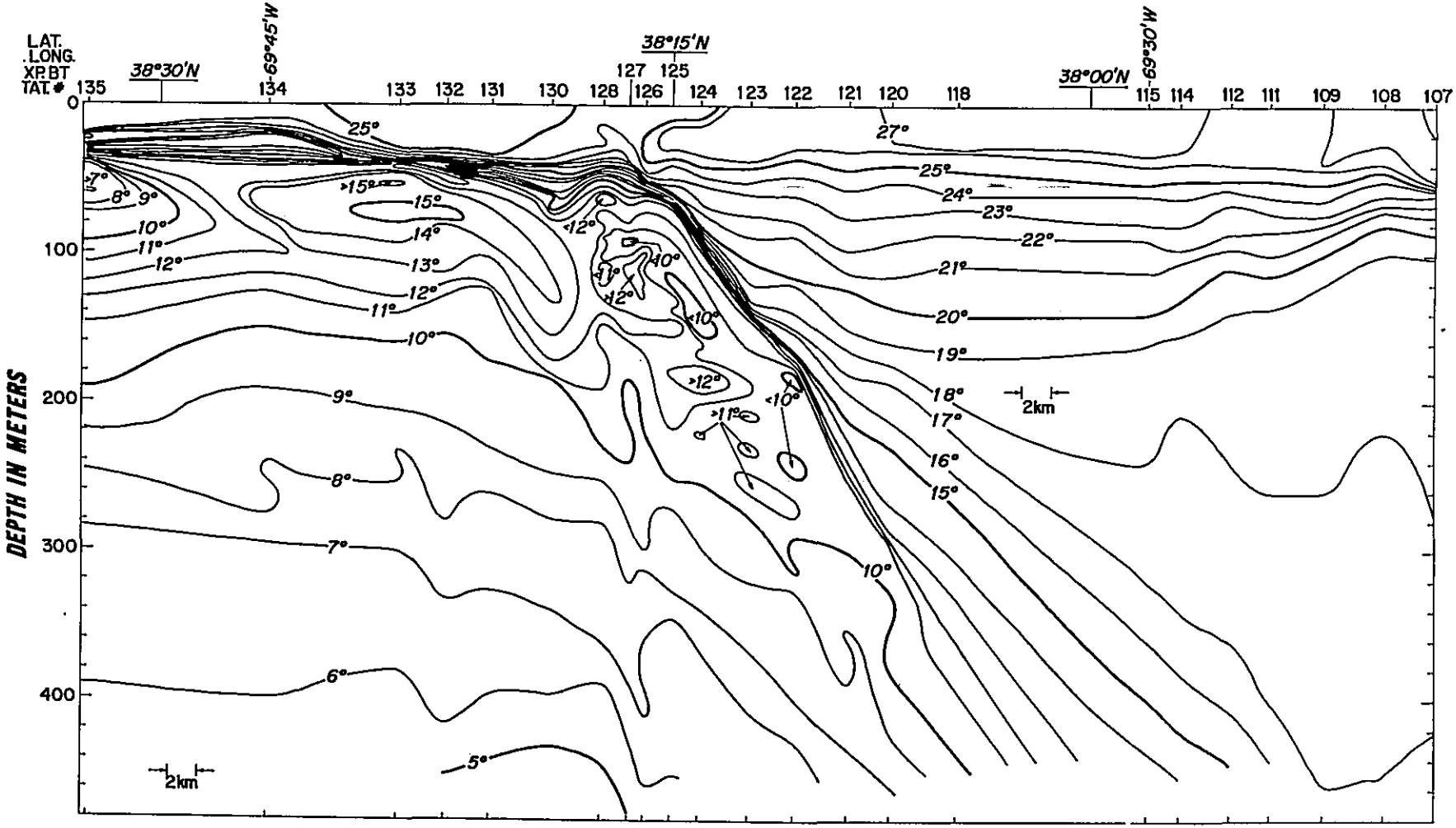

Fig. 1. (Bruce and Stanley) Temperature distribution across the Gulf Stream using expendable BTs from *Atlantis II*, Cruise 23, August 9, 1965.

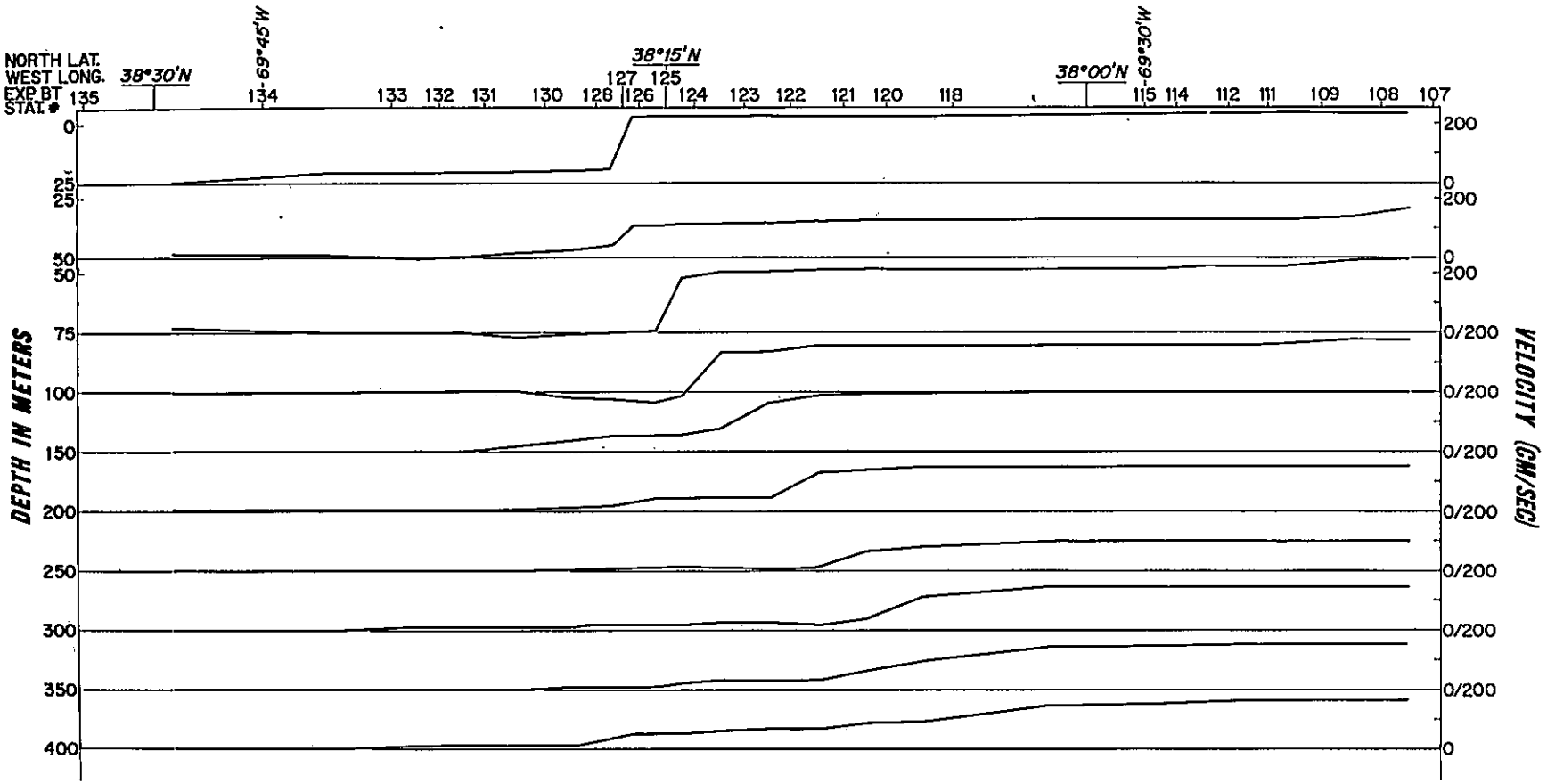

Fig. 2. (Bruce and Stanley) Estimates of current velocity along horizontal surfaces relative to Station 135. Density was approximated from temperature distribution indicated by expendable BTs using Iselin's (1936) T-S relationship for the Sargasso Sea.

WESTERN INDIAN OCEAN CIRCULATION

J. G. Bruce

Using data from recent cruises (1962-1965) in the western Indian Ocean, the near surface dynamic topography relative to 1000 decibars for both the southwest and northeast monsoon periods has been analyzed. Seven zonal sections between 20°N and approximately 10°S allow seasonal comparison of essentially the same areas. The areas of greatest seasonal differences are off the Arabian coast and particularly the Somali coast where the large high (> 1.8 dynamic meters) found during the southwest monsoon is not evident six months later in the northeast monsoon. Figures 1 and 2 show the sea surface topography in the two seasons.

Data from a winter section of direct current measurements and hydrographic stations along 9°N off the Somali coast indicate that although surface currents in this region appeared weak and variable during the northeast monsoon of 1964-1965, the Somali gyre seemed to remain as an appreciable subsurface circulation. The dimensions (350-400 km across east-west) and location off the coast were roughly that of the southwest monsoon gyre, but the current was of much lower velocity (about 50 cm/sec maximum as compared with 300 cm/sec maximum for the southwest monsoon). The volume transport was 55-60 million m^3/sec which is comparable to that found during the southwest monsoon in 1964 by Swallow and Bruce (1966).

Reference

Swallow, J. C. and J. G. Bruce, 1966. Current measurements off the Somali coast during the southwest monsoon of 1964. *Deep-Sea Res.*, 13: 861-888.

AUSTRALIA CURRENT

J. G. Bruce

While on *Eltanin* Cruise 29 (South America to Australia on 28°15′S) a number of direct current measurements (0-1200 m) were obtained between 170°E and the Australian coast to obtain an estimate of flow for the Australia current. Although not yet thoroughly analyzed, the data indicate that generally the currents were weak (under 30 cm/sec) and variable in direction with no well-defined strong current system until within about fifty miles of the Australian coast. There a strong southwesterly current of about 1-1/2-2 kts was found.

EXPENDABLE BATHYTHERMOGRAPH

J. G. Bruce and R. J. Stanley

A short paper was written about the use of the expendable bathythermograph in areas such as the Gulf Stream where, because of the ability to make closely spaced stations (e.g. 1 km spacing at normal cruising speed), some of the small-scale thermal structure as shown in Fig. 1 may be examined, or rough approximations of current velocity and changes of horizontal shear with depth may be obtained (Fig. 2).

WORK IN SUPPORT OF THE U.S. COAST GUARD

C. Godfrey Day

The index of deep-sea, subsurface current measurements was maintained routinely with accessions gleaned from the literature.

Efforts to relate shallow currents to local winds as measured at Sites D and J (see Buoy Program) met with little success. The current records show slow and systematic changes in direction on a time scale that is seemingly unrelated to the relatively rapid changes in the local weather patterns. Changes in current speed alone at times seem to be related to the passage of storms, but too often similar changes cannot be so explained. There are many vexing imponderables in this approach such as the size, intensity, distance, duration and direction of movement of storms which obscure any relationship that may exist.

An attempt was made to relate numerically mean daily current vectors to the local daily wind vectors. Wind direction was expressed by index numbers, either positive or negative according to whether the day's wind was thought to augment or impede the water movement indicated by the current meter record. The index numbers were weighted

to express wind speed and persistence, and a number of correlations were run. Here again results were ambiguous, with the correlations ranging between .18 and .80. Quite uniformly, however, the highest correlations were found when the most favorable wind was considered to be directly down-current, rather than to the left of the current as in the Ekman model.

A study was begun in the Grand Banks region, using the International Ice Patrol computations of transport of the Labrador Current in an attempt to relate changes in volume to atmospheric pressure patterns. Northern hemisphere sea-surface pressure data were obtained in magnetic tape through the courtesy of Mr. Jerome Namias of the U. S. Weather Bureau. The records used begin in 1950 and give twice-daily values of pressure at grid points over the North Atlantic. A program was generated by the data processing group which gives averaged pressures for any period of time desired. It is hoped that the many volume computations from the numerous Coast Guard sections across the Labrador Current can be shown to be related to the pressure patterns.

EQUATORIAL CURRENTS

W. G. Metcalf and M. C. Stalcup

Until the studies of the Equatorial Undercurrent in the Atlantic and Pacific oceans disclosed that the surface current to the westward along the Equator masks a strong subsurface flow to the east, there was little reason to suspect that surface flow over wide areas of the ocean might not be representative of what was going on below the surface. The conventional picture of the shallow currents in the western tropical Atlantic shows a strong Guiana Current carrying South Atlantic Central water along the northeast coast of South America and into the Caribbean Sea.

Work in tracing the origin of the Equatorial Undercurrent suggested that at least in the upper few hundred meters of the water column, important changes take place in the coastal current between the eastern tip of Brazil and the Antilles Arc.

The locations of two sections of hydrographic stations running parallel to the South American coast are shown in Fig. 1. The figure also shows a large pool of fresh surface water whose origin is the Amazon River outflow. In both the hydrographic sections, major discontinuities are found in the profiles of temperature, salinity, density and oxygen which seem to be related to changes in the flow of the coastal current and to the movement of the Amazon River outflow. Figure 2 shows the salinity from Section A. Our interpretation is that the large depth changes in the isohalines in the middle of the section indicate that the North Brazilian Coastal Current which flows to the northwest along the Brazilian coast is turning offshore where it will proceed to the east as the Equatorial Undercurrent. Water from the North Equatorial Current moves in to form the Guiana Current. In the area between these movements, the flow of the current along the coast is thus interrupted and the fresh Amazon River outflow moves offshore.

From the appearance of the discontinuity, it might be thought that this represents a large meander or an eddy in the coastal current. That this is not the case is clearly shown by the fact that the temperature/oxygen relationship of the water on opposite sides of the feature is quite different. As is shown in Fig. 3, Sta. 480 on the right side of the discontinuity has the high oxygen concentrations typically associated with the North Brazilian Coastal Current and the Equatorial Undercurrent. On the other hand, Sta. 492 on the left side has low oxygen values which are typical of the North Equatorial Current. Below about 500 meters, the oxygen differences disappear, and possibly no interruption of the coastal current occurs below this depth.

Reference

Ryther, J. H., D. W. Menzel, and Nathaniel Corwin, 1967. Influence of the Amazon River outflow on the ecology of the western tropical Atlantic. 1. Hydrography and nutrient chemistry. *J. mar. Res.*, 25 (1): 69-83.

VOLUMETRIC STUDIES

A. R. Miller and R. J. Stanley

These studies consist of "planimetering" bodies of water by degree squares, using contoured charts or charts with the latest soundings. Degree squares, for which station data are available, are then assigned observed physical properties and volumes. These are collated. Volumetric T/O_2 diagrams for the Mediterranean Sea have been analyzed

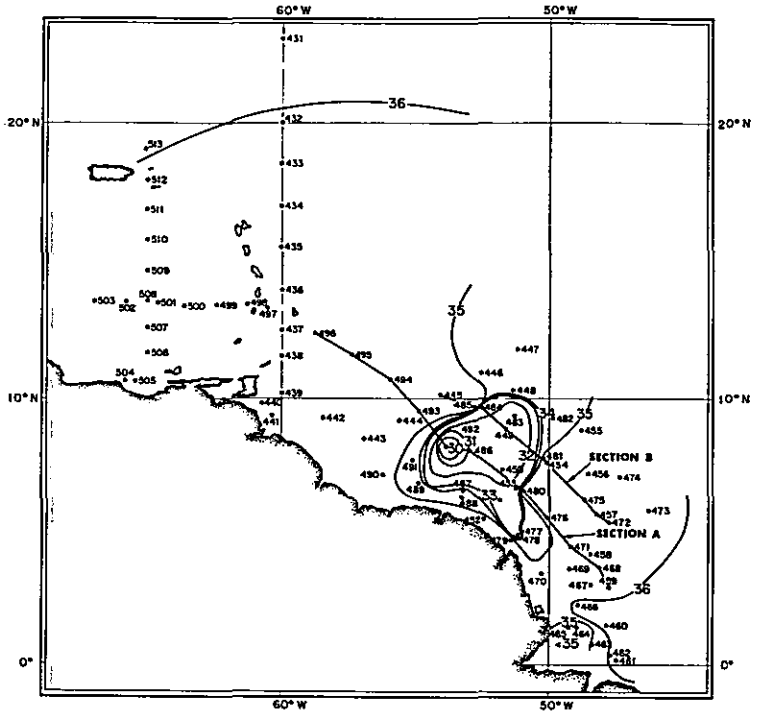

Fig. 1. (Metcalf and Stalcup) Station positions and surface salinity contours for *Atlantis II* cruise 14, Oct.-Dec. 1965 (After Ryther, *et al.*, 1967).

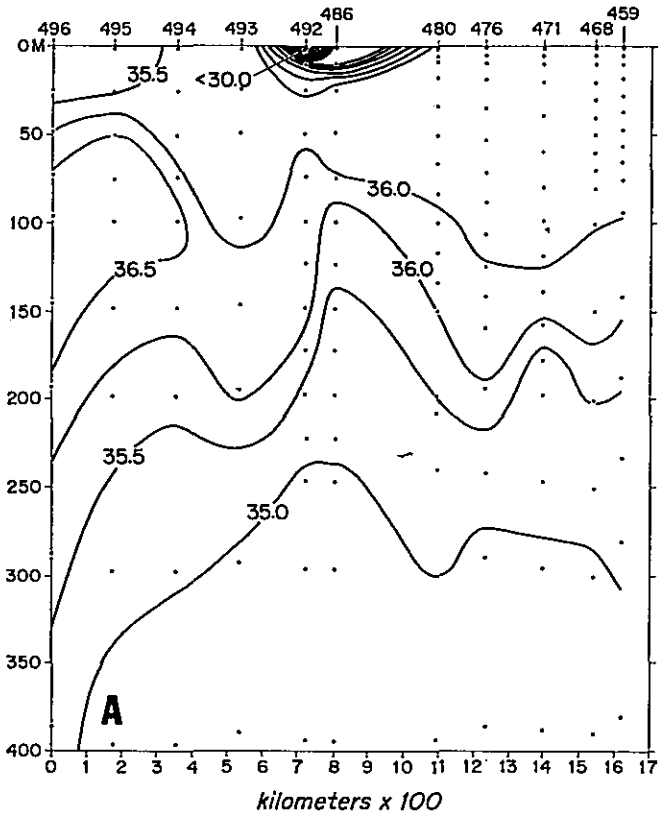

Fig. 2. (Metcalf and Stalcup) Salinity profile of Section A shown in Fig. 1. Vertical exaggeration 1:5000.

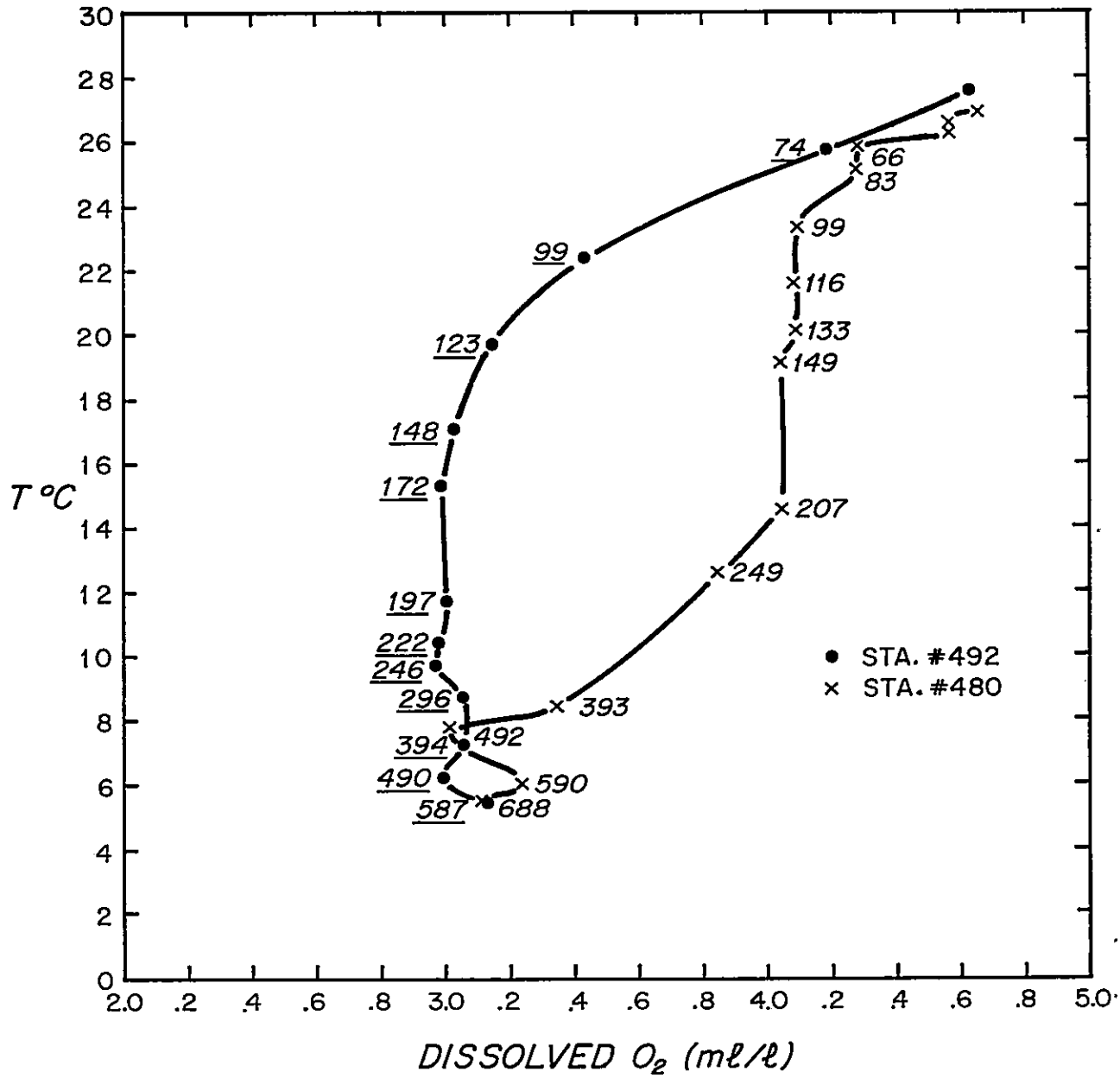

Fig. 3. (Metcalf and Stalcup) Temperature/oxygen relationship of a pair of stations on opposite sides of the major discontinuity in Section A. See Fig. 1 for positions relative to surface low salinity lens: see Fig. 2 for positions within the vertical profile.

in a paper accepted for publication in the *Rapports et Procès-verbaux des Réunions de la Commission Internationale pour l'Exploration Scientifique de la Mer Méditerranée.* During 1967 these studies were continued in the Western Indian Ocean. Data gathered during the two expeditions to the Indian Ocean, *Atlantis II,* Cruises 8 and 15, were used for volumetric analyses. The "planimetered" degree squares have been placed on punch cards and volumes calculated by computer. This has yielded a volume of 90 x 10^6 km^3 for the Western Indian Ocean. This body of water is bounded by Asia to the north, Africa to the west, 80th meridian to the east, and 35° latitude to the south. In terms of topography the volumes are combined into the following basins:

Basins	
Oman	833,015.0 km^3
Aden	343,125.6 km^3
Arabian	16,592,684.7 km^3
Ceylon	16,217,704.0 km^3
Somali	23,276,329.2 km^3
Mascarene	10,409,227.9 km^3
Agulhas	1,490,008.7 km^3
Natal	5,189,202.9 km^3
Madagascar	8,535,881.9 km^3
Crozet	7,480,062.8 km^3
Total	90,367,243 km^3

32° SOUTH INDIAN OCEAN HYDROGRAPHY

R. Munns

One of the sections of the 1965 *Atlantis II* Indian Ocean Expedition was from Durban to Fremantle, duplicating the stations that R. R. S. *Discovery II* had made 19 years previously.

Time did not permit "closing up" the spacing of *Discovery II* stations which were 200-300 miles apart, but by use of her data we were able to improve the "bottle spacing" in order to get important details of the salinity minimum.

The data of both ships are being worked up and analyzed for publication, and are of interest both as a comparison of methods and as part of the understanding of the Indian Ocean.

As to the comparison of the work of the two different ships, the temperature values were practically identical in the deep water. Salinities were remarkably close, considering that *Discovery II's* were titrated at sea and *Atlantis II's* were by salinometer. Oxygens and other chemical titrations were quite different.

Topography:

The section is crossed by many ridges and rises, principally the South Madagascar Ridge, Atlantic-Indian Rise, Mid-Indian Rise and the Amsterdam-Naturaliste Rise, separating the Madagascar Basin, Mascarene Basin, E. Crozet Basin, and Australian Basin. In some cases the ridges have isolating effects upon bottom waters.

Hydrography:

Isotherms, isohalines and isopycnals generally slope upward from west to east. Variations from this trend are due to currents or topography. Surface currents are suggested near the African coast, near Australia and at several places in mid-ocean. The two different surveys show the surface currents changed in position (by as much as 5° longitude), width and depth. The Australian Current is twice the width and half the depth in 1965 as compared to 1966.

The warmest bottom water temperatures are in the Australian Basin where deep temperatures were 1°C, while it was 0.7°C in the Madagascar Basin and 0.5°C in the E. Crozet Basin.

Surface temperatures were about 4° cooler on the *Atlantis II* section, it being 1 - 2 months later in the fall.

Deep currents were shown most dramatically in the Australian Basin with the 1.6°C isotherm level at 3000 meters, rising above that and sharp drop in isotherms in deeper water.

The deep water of Madagascar Basin has a salinity maximum not found elsewhere--greater than 34.82‰ at about 3000 meters.

It is expected that sigma-t - oxygen diagrams will help reveal sources of the various water masses found on this section.

SALINITY AND TEMPERATURE MICROSTRUCTURE

J. W. Cooper

Work continued on the analysis of the data from the Bissett-Berman Salinity-Temperature-Depth (STD) System. Programs were written for the PDP-5 computer which permitted the readout of the STD data recorded on the Dymec digital data acquisition system. The use of digital recording of the direct frequency outputs from the STD has permitted the observations of small scale microstructure which could not be seen in the standard analog output of the STD System. System noise in the analog discrimitor and recorder limit salinity resolutions to about .02‰. In order to realize the full capability of the STD system it is necessary to lower it at a much slower rate than that recommended by the manufacturer: 20-30 meters a minute rather than 80-120 meters a minute. By careful use of the systems and processing of the data, salinity anomalies as small as .005% and 5 meters in depth can be resolved.

Using these techniques observations were made in the main thermocline of the Sargasso Sea off Bermuda. Frequently repeated lowerings of the STD through a depth interval of 50 meters for periods of an hour or so delineated small step structures (see Fig. 1). These are composed of a 5-meter thick mixed region and then a 10-meter thick region in which there is a 0.03 - 0.04‰ salinity change and 0.3 to 0.5°C temperature change. From the drift of the ship, while making the STD lowerings, the horizontal extent of the step structure was determined to be approximately 0.25 to 0.5 miles.

RED SEA BRINES

C. D. Densmore, R. G. Munns, R. J. Stanley

Further work on the Red Sea brines hydrographic data revealed some interesting points.

In *Atlantis II* Deep, there was a temperature increase of 0.5°C in an interval of 20 months, from 55.92°C in 1965 to 56.48°C in 1966. No change of temperature was found in *Discovery* Deep, and no confirmable change of salinity in either.

At the top of the transition zone from normal Red Sea water to the brine, detailed plots show different shapes from day to day, two of them being smooth but having a different angle of slope. A third shows a ragged curve. It is possible that an influx of new brine from below caused the ragged transition that later settled into a smooth and more stable blending of normal and brine waters. This may be evidence of the phenomena causing the temperature change.

There are suggestions that some contradictory measurements from these peculiar deeps may be perfectly valid, within the capabilities of the Nansen bottle. The interface between 44° and 56°C water is so sharp that vertical motion of the surface ship, or even the rotation of the Nansen bottle, can radically change its environment.

A T/S plot of the brines showed that of the two stations on the saddle between the deeps one closely followed *Atlantis* water while the other diverged sharply to follow *Discovery* water. Interestingly, the water on the saddle below 2000 m--both stations--is considerably cooler and less saline than that of either deep.

DIURNAL EFFECT ON SURFACE WATER

C. D. Densmore

Investigation was made of the problems of air-sea interaction and diurnal effect on temperature, salinity and density of the surface layers. Three sections from this work run the length of the Red Sea from north to south (Fig. 1), one in the month of maximum evaporation (February) and another at the time of minimum evaporation (May). The fidelity with which σ_t follows salinity is rather remarkable. Hourly data were used in all cases, and were subjected to harmonic analysis (Summary of Investigations, 1966). Similar work was done for the Baltic after the NATO cruise in June of 1967.

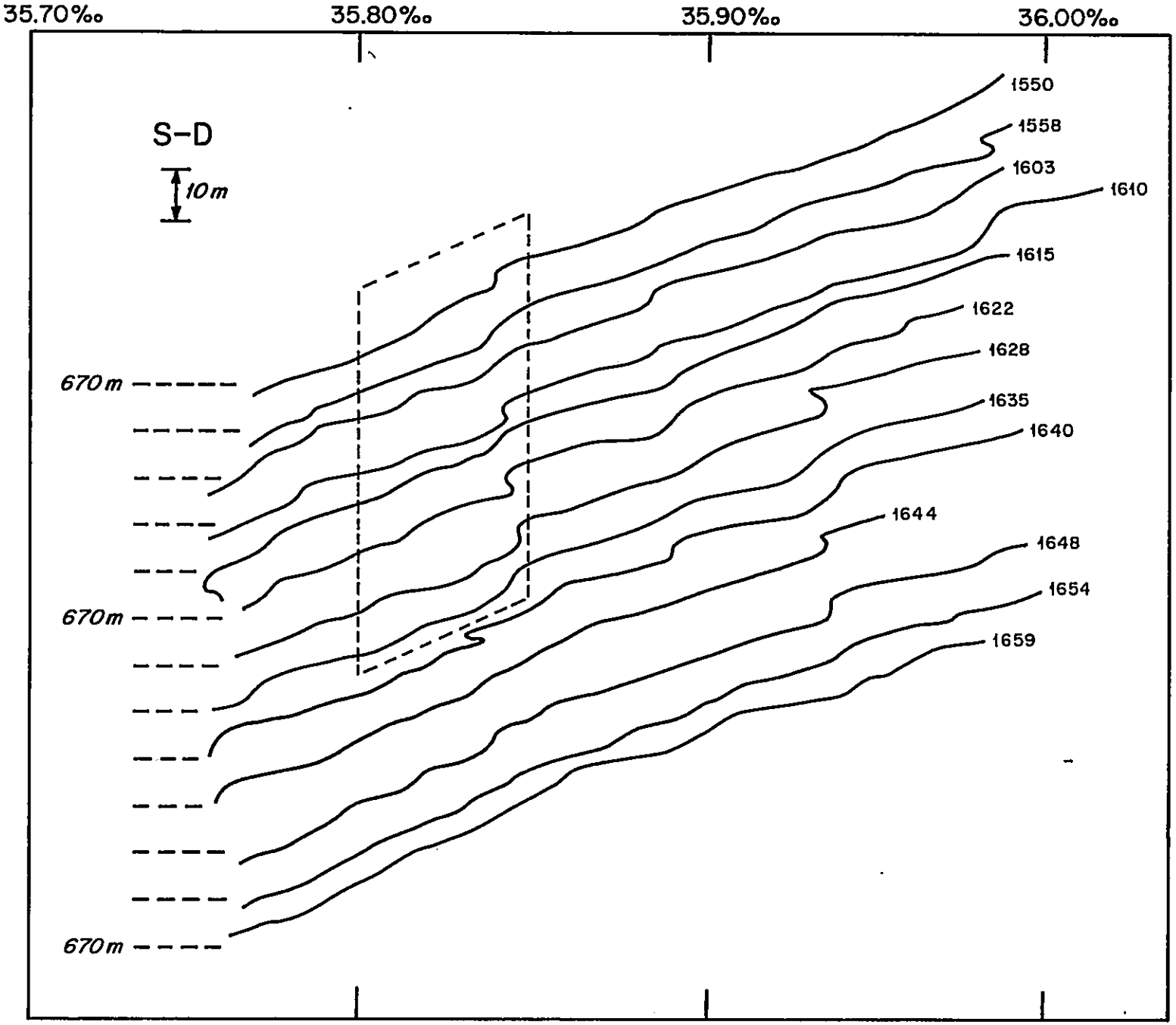

Fig. 1. (Cooper) Salinity-depth microstructure in main thermocline of the Sargasso Sea.

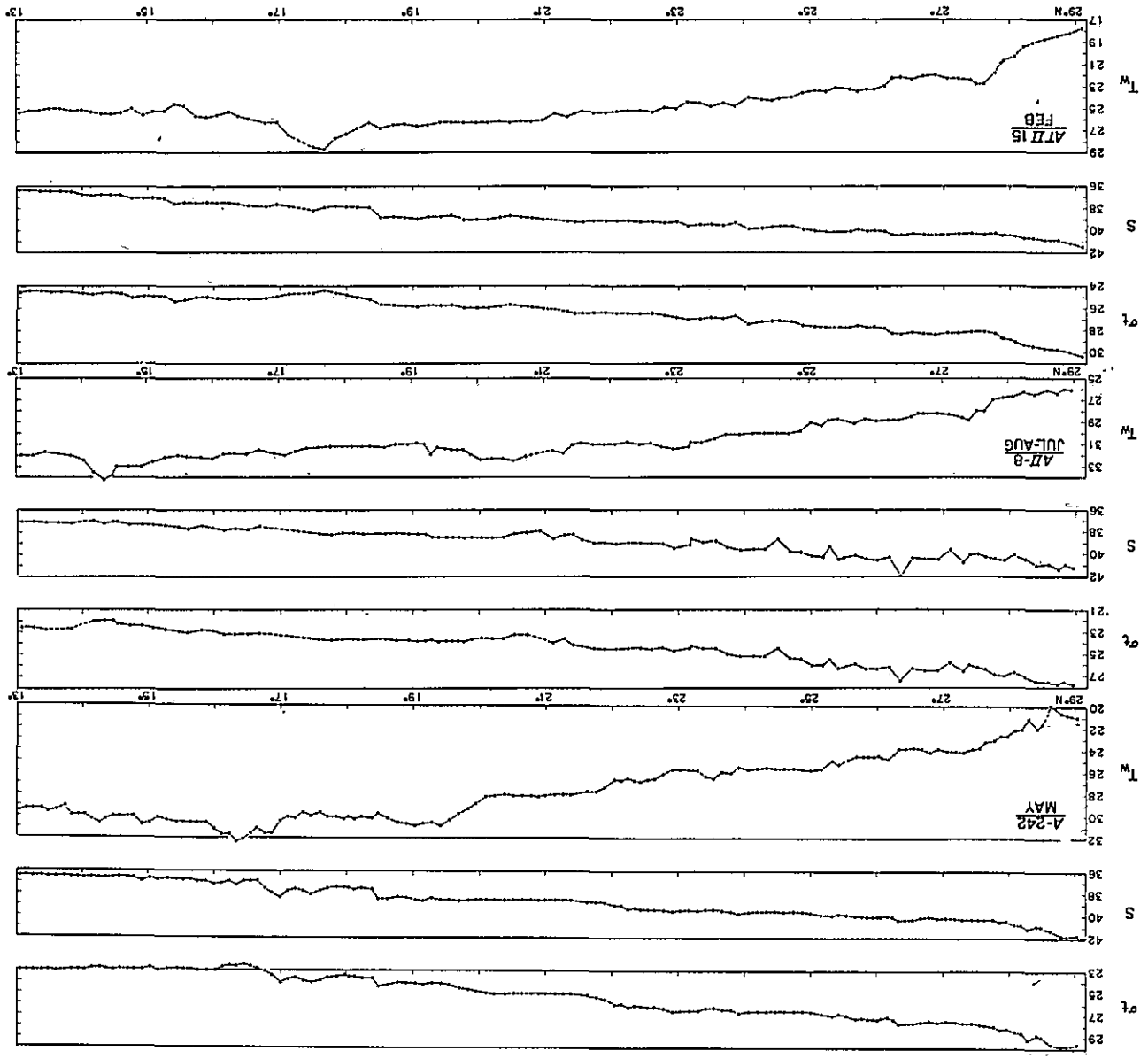

Fig. 1. (Densmore) Three Red Sea sections: temperature, salinity and density.

It is interesting that T/S diagrams of the 24 hourly points of the harmonic analysis in the Red Sea and South Atlantic form an egg shape, with a small appendix where rapid transitions occur, although the Red Sea amplitudes are three times those of the Atlantic. Lines of equal σ_t fit these shapes neatly. Ta-Tw plots for both, at 9 m, 15 m, and 30 m, from hourly BTs, show similar shapes, with progressive distortion with depth.

DATA ACQUISITION AND PROCESSING ON RECENT CRUISES

A. R. Miller

Topics having to do with data acquisition and processing are described in the following summaries. These include: (1) track generator of ships navigation, (2) transfer of PGR data to tape (3) data acquisition development (4) data acquisition systems (5) expendable bathythermograph display (6) solar radiation (7) dew point investigations and (8) a partial bibliography of Mediterranean and Black seas.

TRACK GENERATOR OF SHIP'S NAVIGATION

A. R. Miller

This is a problem in computer graphics wherein digitized data from an XY plotter is transferred to magnetic tape and calculations are made from points flagged along the track. Since the input of data is dependent upon an operator, editing is required to assure the correct format for track generation. A magnetic tape editing program has been devised and applied to the data input.

The entire circumnavigating cruise of *Atlantis II* is now on magnetic tape and in the process of interpretation by a program designed to establish fixes for every navigational event in the history of the cruise. The program has yet to fix positions of course and speed changes but is patently successful in fixing known points in the coordinate system.

TRANSFER OF PGR DATA TO TAPE

A. R. Miller

A system has been designed to read out PGR data from original records and digitize the data suitable for computer processing. A reasonable density of output is planned so that every 200 feet approximately of ship's travel will be accompanied by an echo-sounding observations. Flagging of events such as specified times or special observations are included in the tape storage.

DATA ACQUISITION SYSTEM DEVELOPMENT

A. R. Miller and L. P. Shodin

A system had been installed aboard *Atlantis II* for the Baltic cruise to record the output of various sensors around the ship. In general the scanning cycle was one minute for the following parameters:

Time	Manual input
Bow temperature	Air temperature
Heading	Relative wind speed
Dew point	Relative wind direction
Solar radiation	Port engine RPM
Net radiation	Starboard engine RPM

Experimental logging of Decca navigational data was included.

Voltage sources were monitored and input voltages were regulated to display and record the various parameters in their numerical values.

DATA ACQUISITION SYSTEMS

Leonard P. Shodin

A digitizing capability for the expendable bathythermograph was developed and later used at sea. It included an interface connection to a small A to D converter and paper tape punch and is automatic in its operation with the normal use of the XBT.

A special constant current bridge thermometer was developed for shipboard measurement of air temperature. The output is such that it is readily digitized and recorded using modern computers and data acquisition systems.

A complete multichannel automatic data acquisition system was placed in operation on two *Atlantis II* cruises. The block diagram (Fig. 1) shows the setup for cruise 39. The parameters were recorded on magnetic tape so that computer readout required no numerical translation.

EXPENDABLE BATHYTHERMOGRAPH DISPLAY

A. R. Miller

During 1967 a continuing survey using XBT's has produced a collection of punched paper tapes concurrently with the normal graphic output. These paper tapes are interpreted by programs for the PDP-5 computer. A display system has been devised which displays a series of BT data on an oscilloscope in, essentially, three dimensions where the X-coordinate is temperature, the Y-coordinate is depth, and the Z-coordinate is sequence or distance as required.

The program is designed for visual inspection and manipulation with various options permitting printout or tape storage within selected ranges. These options show an ability to profile a series of BT data according to limits specified by the operator and within the storage capacity of the program (50 XBT's). The program is successful but remains in a developmental stage.

SOLAR RADIATION DATA REDUCTION

R. G. Munns

Strip charts of solar radiation are customarily read by visually integrating 1/2 hourly traces in order to arrive at daily totals. For small amounts of data this is adequate. But when the accumulated records run to many months, as from the long Indian Ocean cruises, visual means are time consuming and dull work.

The Calma 302 Digitizer is being used to solve this problem. The Calma 302 has a cursor with which the strip chart recording is manually traced. Every one hundredth of an inch movement of the cursor in either the X or Y directions puts a pulse on magnetic tape. A computer program translates the tape into hourly integration of $gm/cal/cm^2$ and number of hours per day of measurable solar radiation.

By this means the reduction of records is very considerably speeded up and perhaps the accuracy improved.

DEW POINT INVESTIGATIONS

Robert J. Stanley

In an attempt to measure air-sea interaction, experiments with a thermoelectric dew point hygrometer were carried out in the Baltic in June. These experiments were conducted on board *Atlantis II,* Cruise 32. Although only a small number of experiments were carried out the measurements indicate that the dew point variation, from one to seven meters from the sea surface, is greatest one meter above the surface. The measurements were made during June when air and sea condition were very calm in the Baltic. It is not known how rough sea and turbulent air condition would affect the dew point gradient.

PARTIAL BIBLIOGRAPHY OF MEDITERRANEAN AND BLACK SEAS

B. C. Hays

A partial bibliography of oceanographic literature pertaining to the Mediterranean and Black Seas has been prepared and given very limited circulation. The bibliography is in three parts, the first of which consists of material

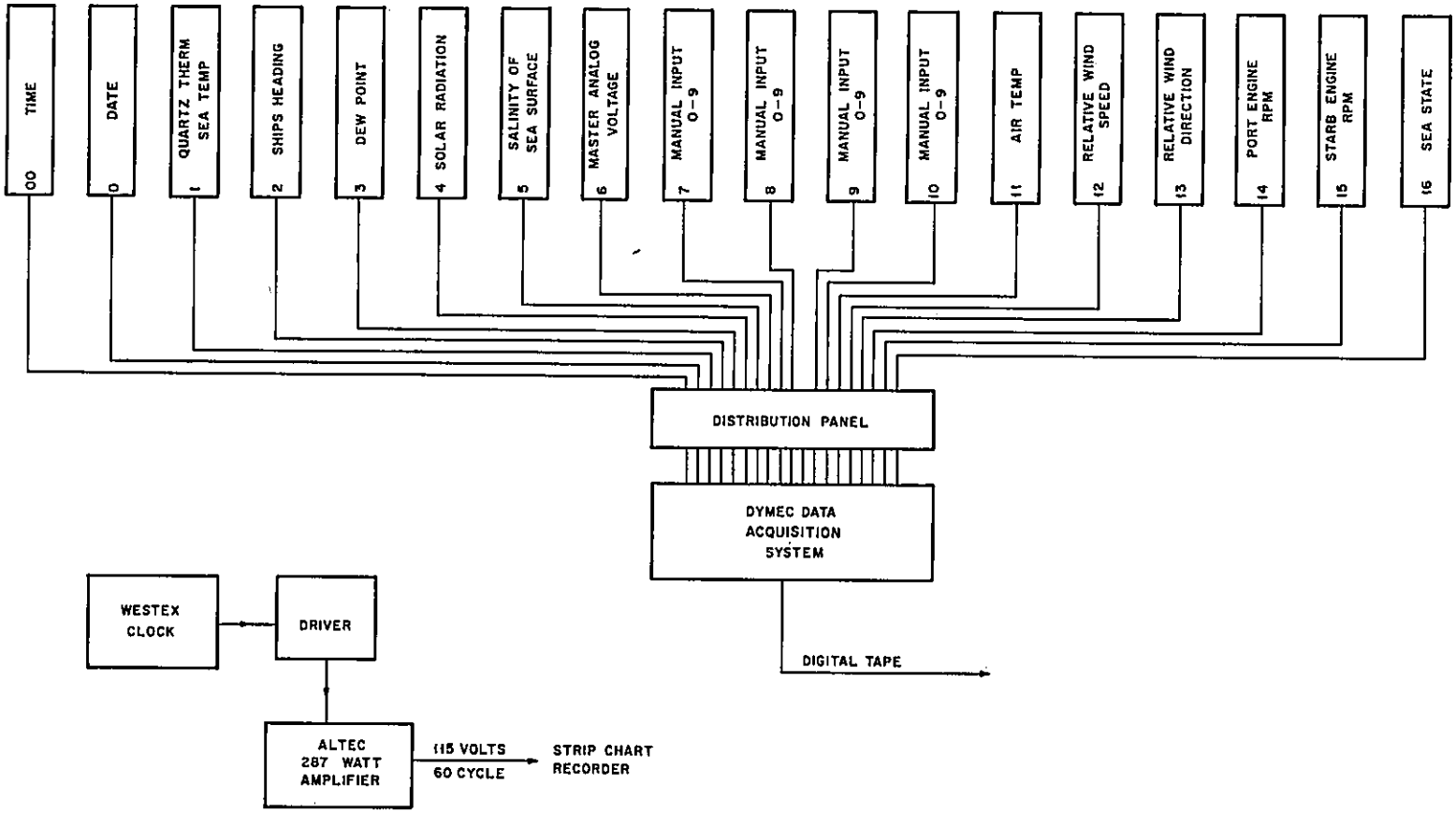

Fig. 1. (Shodin). Multichannel automatic data acquisition system.

checked for accuracy of sources. The second and third parts remain unchecked but, nevertheless, are useful for information. Sources are from the private files of A. R. Miller and Dr. Mary Sears and the library of the Marine Biological Laboratory.

LABORATORY STUDIES OF HEAT FLUX

Claes Rooth, Colin Marks, and Stewart Turner

An extensive series of laboratory measurements of heat flux in a mechanically stirred system of stable thermal stratification was begun in the previous year. These measurements were continued over a wider range of conditions, and with improvements in the equipment, and were finally completed by the end of spring. It has been conclusively demonstrated that in spite of the apparent complexity of the problem, a set of simple basic concepts apply to the problem of transfer between a stratified layer and an adjoining neutral layer stirred by turbulent motions. From the point of view of processes in the mixed layer, the following qualitative picture emerges.

Since vertical transfer of heat changes the potential energy of the system, the total available turbulent energy limits the downward heat transfer. If the stratification is very weak, only moderate damping of the turbulence occurs, and the transition between the mixed layer and the thermocline is diffuse. But increasing amount of basic stratification leads to a sharp splitting of mixed, and stratified, layers. In this case the mixing process also has two stages, an entrainment process at the layer boundary, which is governed by the capability of the turbulence in the overlying fluid to generate internal waves at the interface, and a turbulent transfer in the upper, mixed, layer. Since the latter process drains energy from the turbulent motions, hence decreasing their capability to generate the waves necessary for the entrainment process, a dynamic balance may be achieved. This is in fact observed to happen. The dynamic conditions for this balance are subject of further investigation.

Somewhat related to this problem are investigations of transport effects of bubble streams in stratified, and in rotating fluids, undertaken by Dr. Colin Marks and Dr. Stewart Turner respectively. Dr. Marks had previously worked on heat transport by bubble stream from the point of view of applications to fresh-water ice modification, and bubble-wave breakers. Considering the importance of the source of turbulent energy, and its properties, for the mixing problem, a more precise investigation of the bubble stream case seemed motivated. The experiments undertaken ranged from studies of the wake structure in the stream, to direct measurements of density profile modification. It was found here, contrary to the case where the source of mixing energy is confined to the mixed layer, that a widening of the transition zone always occurs, i.e. the effect of the bubble stream is more of a nature of a uniform induced diffusivity.

Dr. Turner's work relates to the influence of bubble convection, as a fairly well-defined mode of exitation, on the angular momentum distribution in a rotating fluid, in particular to the relative importance of boundary layer and interior flows in this situation. An understanding of this type of internal dynamic adjustment is of potential importance for such seemingly disparate problems as the nature of hurricanes, and of the flow in the Antarctic Convergence region in the oceans.

Less related to the above-mentioned investigations, but of great potential importance for our understanding of water mass modification in ice formation at the quantitative level, is a study by a summer fellowship student, Mr. Robert Pinkel. His work concerned the development of supercooled water under a growing ice sheet on a salt water body. It had been shown on theoretical grounds by Rooth, that appreciable supercooling effects might occur under rapidly forming ice, as a consequence of the exclusion of salt brine, and consequent formation of a salinity anomaly at the ice water interface. A series of careful experiments by Mr. Pinkel has lead to a clear confirmation of this contention, as well as to a suggested rationalization of the mechanism of salt brine inclusion in the ice, capable ultimately of prediction of ice salinities in relation to freezing conditions. The results indicate that the generally observed conditions of supercooling of water under freshly formed Arctic ice is not necessarily connected with convection in the open leads.

Field work:

The preliminary effort to evaluate the usefulness of deep submersibles for the study of small scale dynamic processes in deep water was followed up this year by two series of dives, a total of five descents, in the slope water off Oceanographer Canyon. In addition to the previously developed differential thermal sensor, dye trace techniques were employed to visualize the shear fields in the water column. It was found that shear motions of appreciable

intensity occurred throughout the depths investigated (for various reasons no dives extended below 900 meters). Stereophotogrammetric evaluation of data is in progress, but it can be said already, that velocity gradients over distances of a few meters at a depth of 400 m are of an order of magnitude comparable to that of high frequency components observed in the buoy program at similar depths in the slope water.

Theoretical studies:

The effort to assert the possible oceanic significance of the type of smaller scale motions discussed above has followed two major lines. The structural changes observed by Fuglister to occur in a cut off Gulf Stream ring north of Bermuda during the winter 1965-66 were found to be consistent with a very low level of dissipation and mixing in the eddy interior, and an erosion process operating on the perimeter. A numerical program has been initiated to study the dynamical consequences of various types of dissipative processes on simple symmetric eddy models. This program has been taken over by Dr. Vastano.

The problem of generating a consistent, and quantitatively satisfactory, theoretical description of the phenomena associated with the stirring experiments discussed above, has lead to the finding that the energy spectra for motions in the period range between ca 1 to 10 hours are consistent with a very simple notion of a random assembly of weakly interacting internal waves. This concept carries with it the consequence that the energy distribution in the vertical is controlled by the stability of the water column, and the spectrum form is determined by the generation process (at the top boundary, presumably). It may be a fortuitous circumstance, that a very simple notion of internal wave generation by random high frequency impulses leads to an excellent fit of observed and predicted spectra. The final verdict on this count must await more detailed investigation.

OCEAN ENGINEERING

DEPARTMENT OF OCEAN ENGINEERING

Scott C. Daubin
Department Chairman

DEEP SUBMERGENCE RESEARCH VEHICLE PROGRAM

Alvin Operations in 1967

W. O. Rainnie, Jr.

An extensive refit and modification program was carried out on both the submersible and the catamaran support ship during the winter and spring 1966-67 in order to improve significantly the capabilities of both as described later. A belated start on the first operating season for scientific dives, sponsored by the Office of Naval Research, was made on May 2, when the Navy tug, *Accokeek*, took the catamaran in tow with *Alvin* and embarked for the Tongue of the Ocean in the Bahamas. The launch and recovery system on the catamaran failed on the first launch of the submarine. This necessitated returning to Miami for about one month to make the proper repairs. Upon completion, a return was made to the Bahamas for the post-overhaul test dives and several scientific dives were also then made.

The schedule was compressed to account for the time lost and the catamaran worked slowly up the coast on a diving program designed to arrive at Woods Hole in July. Geology dives were made on Blake Plateau, off Cape Hatteras and off the Virginia Capes as planned. One of the dives on Blake Plateau had to be aborted when a 200 pound swordfish unexpectedly made an unprovoked attack on the submarine on the bottom at a depth of about 1800 feet. The fish became impaled by his sword and was brought back to the surface. No serious damage was sustained by the submarine.

Upon return to Woods Hole, local dive series of five to eight days each were made to various parts of the continental shelf and slope south and east of Woods Hole. Several canyons were visited for geological observation. Several dives were made on the shelf to observe the fish population and to correlate direct observation of the bottom with side-scanning sonar records. Biological dives were conducted to the operating depth limit of 6000 feet and shallower. Studies were made of the micro-thermal structure of the water above the slope, as well as identification of the major constituents of the deep scattering layer known as "Alexanders Acres." Acoustic measurements were made of the "Sparker" by *Alvin* on the bottom and during the return trip to the surface.

While in the process of being recovered on one of the dives south of Martha's Vineyard, a handling line became fouled on the catamaran and the resulting collision between *Alvin* and the catamaran dislodged the mechanical arm which plunged to the bottom in 4400 feet of water. Three weeks later, the submarine returned to the same location and was successful in finding and recovering the lost device. Fortunately, the arm sustained little damage and will be restored to normal operation soon. A major instrument development program sponsored by the Naval Oceanographic Office was commenced early in the year. The major development goals include: improved sampling devices and techniques; an improved underwater navigation system; and a submersible mounted instrument package for routinely recording on computer process tape sound velocity, temperature, depth (pressure), and salinity (option-conductivity). Progress has been made in all of these areas and "hardware" should be available for use in the scientific diving program scheduled for 1968, thus enhancing the scientific capability of the deep research program.

In summary, fifty five (55) dives were made this year broken down into general categories as follows:

Geology	17	Geophysics (Acoustics)	3
Biology	20	Navigation	2
Physical Oceanography	3	Testing and Certification	10

The major impediment to performing more dives than this remains and that is the weather and sea state limitation on our present catamaran support vessel. Considerable effort has been made to obtain the necessary support to make improvements in this direction, unfortunately with little success to date.

Modifications to *Alvin* and Catamaran

Frank P. Omohundro

Alvin:

The most extensive modification program to date was accomplished on *Alvin* in 1967. No system was left unchanged and some additions were made. All the modifications resulted from recognition of deficiencies in operations, followed by engineering studies of improved methods. Objectives of the modifications were improvement in reliability, maintenance, efficiency, and effectiveness of *Alvin*, with the overall objective of increasing *Alvin's* utility to scientists. Operations during 1967 proved that the expected improvements had been achieved or surpassed. The foregoing is not meant to imply that still other desired improvements are not recognized. Time and funds available will always be limiting factors; but it is expected that *Alvin* will continue as a developmental prototype. Solutions from *Alvin* of "how to do it" are constantly being applied to other deep submersibles being designed and built. The changes in *Alvin* were too extensive to even list them all in the space allocated here, let alone describe them. The major changes were as follows: (1) The new bow and lower skin are the most visible changes. The new bow, of syntactic foam, changed the silhouette, added length, and increased payload. (2) New batteries in a new arrangement improved endurance and made more energy available for scientific purposes. (3) Titanium spheres, with the same collapse depth as the personnel sphere, replaced two aluminum types to eliminate corrosion worries. (4) After extensive testing new lift propellers were selected which provide greater thrust. (5) Descent and ascent weight droppers were added to give more time on the bottom.

Catamaran:

As with *Alvin*, an extensive modification program was undertaken on the mother ship. The objectives of this program were to increase or improve the efficiency and safety of operations, increase endurance and range, and increase the utility to scientists. The success achieved with this program was not commensurate with the *Alvin* program; furthermore, some of the modifications had to be done over during a one month interruption in diving operations. The final result was a considerable improvement over the previous year; however there are still many improvements readily identified, and some features are still unsatisfactory. The major modifications were: (1) A better navigation radar was installed. (2) The 35KW diesel-generator was replaced by a 60KW set. (3) A main hydraulic system was installed. This is comprised of a pump driven by power-take-off from each D-G set, two electric booster pumps, a heat exchanger, reservoir and distribution manifold. (4) The electric steering motors were replaced by hydraulic systems on each propulsion unit. (5) A deckhouse forward on each hull replaced the trailer on the bow. (6) The electric anchor windlass was replaced by one hydraulically operated located forward. (7) Additional fuel storage and a fuel transfer system were installed. (8) A large built-in food freezer was installed in the starboard hull. (9) An improved, hydraulically-operated, bridge-controlled submarine tracking tower was installed. (10) A photographic laboratory was built in the starboard hull. (11). The travelling hoist was replaced by a hydraulically operated derrick. (12) The all-welded radio and radar mast was replaced with one of clamped-tubing type and a single pole was added forward for the masthead light. (13) The submarine hoist system was changed from electric drive to hydraulic drive. (14) A chilled-water air conditioning system was installed in the port deckhouse for the galley-messroom. (15) Four bunks were added.

SAMPLING

Underwater Vehicle Lighting

C. L. Winget and M. J. McCamis

Scientific and photographic missions during the 1967 dive season, have shown that no single lighting configuration mounted on the vehicle will provide the proper illumination for all missions. As experience was gained, the flood lamps were continually moved, repositioned, focused, and varied in wattage to provide the best possible illumination for each area of scientific investigation. As the season progressed it became quite clear that the port window was the preferred position for visual observations, while photographic missions were satisfactory from either window. Flood lamps have now been designed with mounting configurations that allow them to be easily positioned about the vehicle, depending on the requirement.

In addition to the vehicle-mounted lights, a boom assembly has been designed to provide a 750 watt floodlight, located approximately 10 to 12 feet away from the vehicle. The boomlight assembly may be mounted over either of the three windows, and is capable of being surface swiveled fore and aft, as well as up and down. The boom has been provided with an electrical, quick release mechanism that may be activated by the pilot in the event the assembly becomes entangled during bottom operation.

An externally mounted strobe light, synchronized to a single frame hand-held camera, has been designed to provide the scientist with the capability of obtaining improved bottom photographs. The strobe lamp assembly may be positioned at either of the three viewing windows prior to a dive. It will automatically be synchronized with the hand camera shutter, and may be fired once every 12 seconds. This installation supplements the two E. G. & G. Co. Inc. 35-mm strobe and camera assemblies mounted at the bow of the vehicle.

Mechanical Manipulator:

As a result of difficult wind and wave conditions encountered during a vehicle recovery, the mechanical manipulator was sheared from the submersible when it hit the stern of the starboard pontoon of the catamaran. The manipulator fell to the bottom in 1300 meters of water. Fortunately, the catamaran and the support vessel both obtained a position fix at the drop point. The accuracy of the fix allowed the submersible to return to the exact point of the loss, two weeks after the initial drop, and to recover the manipulator after three search attempts.

The loss of the manipulator prompted the design and fabrication of a quick release surface dropped bottom marker for use in laying out search patterns and/or bottom navigation problems. The marker consists of a lead nose cone, a syntactic foam float, expanded metal sonar target, and a 37 KHz water activated pinger having a 21 day life. In operation, the assembly is dropped from the surface vessel at the desired drop zone. As the marker falls through the water, the nose cone and float are mechanically detached. As the nose cone continues to fall, a 200-foot length of nylon cord is unreeled, allowing the pinger, expanded metal sonar target, and 37 KHz pinger to trail behind. On bottom contact, the float remains 200 feet above the bottom, providing a good sonar target for a submersible engaged in a search mission.

In addition to the surface dropped pinger marker, the submersible has been provided with a vehicle mounted 37 KHz pinger dropper. The pinger may be released at the pilot's discretion, providing him with a means of homing-in and returning to the precise area at some future time.

Specimen Samplers and Scientific Apparatus:

The following items of scientific apparatus were used during the 1967 dive season: (a) Water samplers, operated by the mechanical manipulator, provide the scientist with specimens of either water or bottom silt at specific areas selected by him for investigation. (b) Coring tubes for unconsolidated and semi-consolidated sediments. The apparatus is operated by the mechanical manipulator, and provides the scientist with cores approximately 24" long. The plastic tube construction provides the scientist with a visual observation of the sample while he is still on the bottom. If he is not satisfied with the specimen obtained, it may be discarded and another core sample taken. (c) Plankton nets with flow meters have been attached to the vehicle to provide either mid-water or bottom specimens depending on the desire of the science personnel. The net may be opened or closed through the use of the mechanical manipulator, providing the scientist with selective sampling. (d) Fish traps, mud rakes, bottom current meters, drifters, as well as dye pellet markers, either with negative, positive, or neutral buoyancy, are available for bottom and mid-water observations.

Development Programs in Progress:

Hard rock coring tools are being developed to provide the scientist with 3/4" diameter by approximately 4" long rock cores. The coring device is a rotary drill, self powered, and operated by guiding it with the mechanical manipulator.

A second type of core devise is being investigated. It is a resonant powered coring tool, and has the added advantage of not producing an opposite torque reaction during its drilling cycle. The lack of torque is a distinct advantage when obtaining a rock core specimen while the vehicle is hovering in a neutral buoyancy state along the side walls of a cliff.

A live specimen retrieval capsule is in fabrication. It is a one liter chamber, and will provide the capability of retrieving a specimen from depths of 1800 meters. Its construction will keep the specimen at the pressure and temperature, found in its natural bottom habitat. Designs are being completed for a high pressure salt water aquarium, that will provide a means of transferring the bottom life from its capsule to the observation chamber for further evaluation.

BUOYANCY AND PROPULSION

Titanium Buoyancy Spheres

Arnold G. Sharp

Fifteen buoyancy spheres of titanium alloy were manufactured and installed in *Alvin* as replacements for the original aluminum alloy spheres. Six of these are part of the variable ballast system of *Alvin*, while the remaining nine are incorporated into the fixed buoyancy packages. One of the fixed buoyancy spheres is now used for storage of the compressed air required for blowing the main ballast. This eliminates the need for the SCUBA bottle previously carried for this purpose.

The spheres were manufactured from closed die hemispherical forgings of Titanium Alloy 6 A1-4V, annealed, machined, and welded with a single "TIG" weld. Extensive metallurgical and mechanical testing was done on samples taken from all the hemispheres. Dye penetrant, ultrasonic and radiographic methods were employed to inspect the machined hemispheres and the finished welds.

Two extra spheres, manufactured to the same specifications, were pressure tested to destruction. Of the two, sphere S/N 0005 collapsed at the lower pressure, in a creep-induced, ductile type, buckling failure at 7800 psi (equivalent to a depth of 17,500 ft.) At the 6000 ft. operating depth of *Alvin*, this represents a factor of safety of about 2.9, approximately the same as that for *Alvin's* main pressure hull.

New Buoyancy Material:

Early in 1967 a package of syntactic foam buoyancy material was added to *Alvin's* forebody. This is located principally at the bow of the vehicle in an area at and slightly below the waterline. The new material weighs 863 pounds, displaces 1505 pounds of water, and thus provides 642 pounds of additional lift. This increased lift has enabled *Alvin* to operate during 1967 carrying three persons plus the mechanical arm, and has made possible a significant gain in scientific instrumentation payload.

The stability of *Alvin*, surfaced and submerged, has been improved by the new syntactic foam package. Values of GM (metacentric height) and BG (distance of center of buoyancy above center of gravity) now average 20-30 percent greater than those values reported in 1965. Values of GM and BG were determined this year by careful inclining experiments with *Alvin*, and also from a complete weight-stability computation performed with the assistance of the Institution's Information Processing Center.

Propeller Tests:

Also completed in 1967 was a series of tests of propellers with and without flow-accelerating (Kort type) nozzles, in an effort to evaluate the existing side propulsion units of *Alvin* and to determine how their performance might be improved. Static thrust measurements were taken under various conditions of pressure and flow to the hydraulic driving motor, for a series of unshrouded propellers and for the actual *Alvin* side propulsion units. Principal conclusions drawn from these tests were: (a) The present propeller-duct combination used in the *Alvin* side propulsion units provides a static thrust which is about 17 percent greater than that of the same propeller, unshrouded. (b) The use of a propeller blade shape such that the blade end conforms closely to the inside wall of the duct results in an additional 14 percent gain in static thrust. (c) A propeller somewhat larger than the present 14 X 20 inch wheel would be a better match to the existing hydraulic propulsion system. Tests indicated that a diameter of 18-20 inches with a pitch-diameter ratio of about unity would be optimum.

Progress on *AUTEC I*

Rees Williams and Valentine P. Wilson

In the first part of 1967, it was found necessary to make many engineering changes in the design of the *AUTEC* Vehicle. This involved changes recommended by the staff at Woods Hole, as well as changes found necessary by the designer and builder, Electric Boat Division of General Dynamics. The building contractor had reported to NAVSHIPS, that as a result of the exacting Navy Specifications, the weight estimate of the vehicle would be 20.5 long tons, vs. 17 long tons specified, and that the vehicle volume as defined in the contract line drawing was not sufficient to include enough buoyancy material to float the vehicle. Electric Boat's recommendation at this time was to lengthen the vehicle 3.5′ with a resulting total weight of 22 long tons. A series of conferences were held in February, during which WHOI personnel made numerous recommendations for weight reduction which were based on successful experience with *Alvin*. The Institution's recommendations would have held weight to 18.5 long tons without lengthening and were as follows: (1) Reducing skin from 3/16″ to 1/8″ thickness. (2) Using 36#/cu ft syntactic buoyancy blocks instead of 38#/cu.ft. (3) Delete navigation computer and associated equipment. (4) Add sponsons to the forward portion of the vehicle to allow for additional flotation material installation and provide protection to the side propulsion motors. (5) Change batteries from iron clad to flat plate type. (6) Delete cathodic protection system plus many other minor weight-saving methods and equipment.

The final approach was agreed upon in a conference in NAVSHIPS in mid-March, attended by representatives of Electric Boat Division, SUPSHIP Groton, NAVSHIPS, Office of Naval Research and The Woods Hole Oceanographic Institution. The compromised agreement resulted in a lengthening of the vehicle by one foot and a few other reductions which resulted in a vehicle weight of 20.5 long tons. The final signed contract for this change was received by Electric Boat in September 1967. The end result was an increase in cost and an extension of the delivery date from December 1967 to August 1968. This latter date will now be extended to November 1968 due to continuing engineering changes and production delays.

The result of the increase in weight and size of *AUTEC I,* will also require changes in the hoist and cradle arrangement of the catamaran, plus more buoyancy in the hulls.

The present status of construction of the *AUTEC* Vehicle is as follows: the personnel sphere was pressure tested to 3180 psi, equivalent to a water depth of 7150 feet by the Naval Ship Research and Development Center in April 1967. Since then 15 repairs have been made on the welds. A very strong effort was made to have the sphere retested after these repairs but this did not meet with success. The submarine frame is scheduled for completion by February 1968. System sub-assemblies are in various stages of completion from just approved drawings to completed units.

The process of changes, in equipment and design is still continuing with a major change recently approved for a portable oxygen bottle system from a fixed oxygen system. Changes still being negotiated, at year's end, include an increase in the exterior lighting from four to nine lights, a simplified weight dropper arrangement, a more manageable hoisting sling, and several basic engineering changes to insure a safer, and simpler operational vehicle.

As the progress of construction of the *AUTEC* Vehicle increased, a full time Institution representative, has been at Electric Boat since August to provide liaison between the Electric Boat Company, the Office of Supervisor of Shipbuilding, and the Institution.

Instrument Group Activities

William M. Marquet

During 1967 a major redesign, augmentation and rearrangement of the instruments within *Alvin* was completed which have resulted in making the vehicles' instruments of more value to the scientists, a significant improvement in window accessibility, an increase in the provisions for users equipments and a general increase in habitability.

An extensive two year DRV associated instrument development program was initiated jointly with the Electronics Section of this department. The major parts of this program are directed toward development and test of (1) an underwater navigation system; (2) a water sensor and data recording system, and (3) equipment for obtaining marine samples using a DRV.

The new precision depth sensing and digital display system installed in *Alvin* during the year provides an order of magnitude improvement in accuracy and readability over the previous system. On two successive dives to an identical 1823 meter location, a repeatability of one meter was obtained.

Equipments were installed and tests conducted to improve the acoustic navigation-tracking capabilities between *Alvin* and the catamaran. A prototype stable frequency 4 KHz pinger was mounted on *Alvin* during the majority of the diving season and was successfully used to provide a nearly continuous record of the range to the supporting catamaran using one-way acoustic ranging techniques. A tracking transponder was also carried by *Alvin*. It is believed that the relatively high and variable broad band vehicle noise caused the difficulties experienced in reliably triggering this unit at ranges in excess of 1500 meters. At the end of the diving season, as a joint WHOI-U.S. Naval Underwater Sound Laboratory project, measurements were made of the noise radiated from *Alvin* when submerged.

During the year, the *Alvin* instruments used jointly by the scientists and the pilots were converted to metric units.

The photographic capabilities aboard *Alvin* were expanded during the year. The results were somewhat variable. Many lessons were learned about the problems of consistantly taking high quality pictures from a DRV. A program for improvement in the area is being initiated.

The instrument group's responsibilities included the at-sea service and maintenance of the control and instrument suit aboard *Alvin* and the electronic equipment aboard the catamaran. Services are also rendered to the *Alvin* user-scientists. The preventive maintenance program was a factor in achieving the best record to date in reliability of the sea going electronic equipment. The sophisticated continuous transmission frequency modulated (CTFM) sonar installed on *Alvin* was routinely serviceable during the operating season and leads the list in improvement of the reliability.

BUOY ENGINEERING-MOORING SYSTEMS

H. O. Berteaux and P. B. Stimson

Mooring Lines

Engineering efforts have concentrated and will continue to concentrate on a better understanding of the causes and modes of failures of the mooring lines of deep sea buoys and on the improvement of their design. In early 1967 computations and measurements made at sea confirmed the need for increasing the size and ultimate breaking strength of the wire rope used in surface moorings at the time. A new type of mooring line assembly with greater strength and more corrosion protection was developed and manufactured. This type consists essentially of an aircraft construction wire rope with double protection against corrosion: aluminum or zinc coating of the wires and polyethylene jacket over the rope. The end terminations, galvanized and waterproofed are tapered swaged fittings covered by a vibration damping boot. This configuration originated at the Institution was adopted by industry as a "standard" buoy cable and was on display at the 1967 Buoy Symposium in Washington, D.C.

A total of 16 moorings, 7 long term (2 months) and 9 short term (2 weeks maximum) were set in 1967, using this type of mooring line. Whereas the short-term moorings were 100% successful, the disappointing performance of the long-term moorings (two moorings retrieved out of seven set) pointed to the necessity for re-evaluation and further study of the mooring line concept. (1) Measurements and correlation of the exciting functions (currents, winds, wave action) and the resulting loads on the mooring line (static and dynamic tension, vibration, jerk, etc . . .) are to be made during launching and on station at specific times and at different depths. (2) A complete evaluation program of mooring line material and geometry. (3) There will be experimentation with wire rope handling techniques. (4) A better theoretical analysis of the shape and stresses in the present taut and compound mooring configuration will be undertaken.

Part of this ambitious program was implemented during the second half of 1967. A surface buoy (JUMBO) specifically designed to support and house engineering parameter sensors and recorders was built. Preliminary selection of parameters of interest and determination of their range has been made, and the selection of sensors has begun. A preliminary review of the methods of analysis of mooring lines was made, which confirmed the lack of adequate

analytical tooling. The finding of an Institution mooring line adrift, prompted the formation of an investigative panel with participating engineers and metallurgists from the Massachusetts Institute of Technology, the Preformed Line Products Company and the Bergen Wire Company. This panel will report in early 1968 on the modes and possible causes of failures of the parted line.

The two retrieved long-term mooring lines were systematically tested. The tests did not reveal any sign of deterioration due to fatigue and/or corrosion and may indicate other causes of failures. Nearly a hundred terminations of the type described have been tested successfully.

In order to evaluate and compare *in situ* the performance of mooring lines of different types (aluminized, galvanized, bare, covered, stiff terminations, flexible terminations etc.) a "shallow water" test experiment has been started. Selection and manufacture of test samples, design of surface floats and loading weights, specifications of retrieval means are presently taking place. The first "test mooring" should be implanted in 120 feet of water by mid-February 1968.

Mooring Hardware

A newly-designed surface float has been built and tested. It is of conical shape, 10-feet in diameter and 4-feet in height constructed of foam-filled welded aluminum. The 12-ft. aluminum mast is 7 inches in diameter and houses the buoy's power supply, instrumentation and transmitter, affording good protection from the elements.

The buoy has been observed at sea in heavy weather, and appears to ride very well. Because of a previous experience with a similar (but smaller) buoy, in which a current meter at 10-meter depth showed inexplicably high noise level, a special current meter with a high sampling rate was installed under the new buoy. It is hoped that the nature and the source of the noise will be revealed.

Back-up Systems

The need for a back-up system which would bring back to the surface the broken mooring part left on station with its valuable information and lost instruments has long been recognized by frustrated scientists and buoy engineers. Dragging attempts being unfruitful, an "active ground line" was conceived in early 1967, and its components designed and fabricated. Such a line was set 4 times without success in retrieving the bottom anchor. Every time the syntactic foam buoy did bring the line to the surface, but tangling and possible chafing on the ground, as well as difficulties of handling four miles of line under high tension and rough seas resulted in the break of the ground line.

Further testing with buoyant ground lines and without attempting to raise the main anchor will be made in 1968.

To palliate the difficulties mentioned, buoyancy elements could be incorporated in the mooring line itself. These elements, combined with a reliable acoustic release, could constitute a good back-up system. Such an alternate system is being engineered and will be set at sea in February 1968 for evaluation.

INSTRUMENT DEVELOPMENT

Paul B. Stimson

Numerous recordings of mooring cable tension have been taken over the past several years. In general, the records have been recovered only from the successful moorings; the loss of data from stations which went adrift has been a continuing source of frustration. A system of cable tension telemetry has therefore been designed, and has come into general use during 1967. Night-time reception over distances as great as 700 miles has been achieved, using only 2 watts at 2398 KHz. The telemetry encoder is being modified so as to transmit surface current speed and direction as well.

Cable tensions continue to be recorded at the buoy. During the year, a pressure-compensated tension transducer was developed; it is now possible to record tension at selected depths along the cable.

A depth telemetry device has been developed, and was installed and tested in one of our standard acoustic beacons. It makes possible the measurement of rates of ascent and descent of elements of the mooring system, and has already produced valuable new data.

Other developments include a 4-inch diameter Tape Transport with 10,000-foot tape capacity, an endless-loop 16-mm instrumentation camera with more than 300-foot capacity, and a new line of solid state timing devices with an accuracy of 5 parts in 10^6 for use in current meters, acoustic releases, etc. All are nearly ready for sea trials.

Because of continuing evidence that corrosion plays some role in the failure of mooring cables, new corrosion-resistant alloys are being investigated. These materials have mechanical properties similar to those of steel, but their corrosion rates are at least two orders of magnitude lower. Only a modest improvement in recovery rate would be required to offset their high cost. The most promising of these new alloys is Inconel® 625.

In order to evaluate in a quantitative way the performance of mooring lines, tests reproducing the mechanical loads of cyclic tension, shock, and vibration encountered at sea must be performed under controlled laboratory conditions. A company with unique wire rope testing facilities (Preformed Line Products Co.) was contacted, a preliminary outline of a test program was made, and testing of the wire rope used at sea in 1967 will start in early 1968.

A universal testing machine has been selected and its delivery in 1968 should significantly add to the Institution's limited testing capability. The review of the tension data recently acquired, the further and better engineering measurements to be made at sea in 1968, the evolution of the test programs contemplated will permit a much better understanding of the performance characteristics and limits of the mooring lines presently available and of the causes of failures at sea. Improvement in the design and the reliability of the mooring lines will then become much easier to achieve.

INSTRUMENTATION

D. C. Webb and R. G. Drever

A joint program continues between the Institution and Massachusetts Institute of Technology for deploying long range Swallow type floats having an operational life of one year. The experiment is primarily a study of oceanic circulation.

A precision depth indicator system was developed and is now in routine use on *Alvin*. The indicator has an overall accuracy of 0.3% and a repeatability of 0.5 parts in 10^3. Depth is displayed on a digital display to a resolution of 0.5 parts in 10^4. The indicator has been used successfully to return *Alvin* to within one meter of depth from one dive to the next.

A comprehensive system for measurement and digital recording of environmental and experimental parameters (*Alvin* Ocean Sensor and Data System) has been developed (Fig. 1). This system was designed to our specifications to meet as wide a range of scientific problems as possible consistent with operating in the confines of a small submersible. It has a deep water capability of 20,000 feet with its deep water housing.

Temperature, pressure, sound velocity and salinity or conductivity of the environment will be measured and recorded routinely, as well as the time of observation and navigational data. These measurements may be selected and displayed in scientific units to the personnel aboard the submersible, and will also be recorded in computer acceptable digital format on magnetic tape. Additional recording channels are provided for other experimental data.

The equipment has been tested and will be in use during 1968; it represents the most advanced state of the art integrated sensor and data system yet developed. The system was designed and constructed by Bissett-Berman.

A complete underwater acoustic navigation system for both *Alvin* and the surface ship is under development. The technique employed is broadly similar to that tested on a small scale during 1965 and 1966. Six underwater marker beacons have been completed and have undergone limited trials with the submersible. The receiving and display equipment for both the submersible and the surface vessel are still under development. The first complete system trial will take place early in 1968.

A joint program for deploying swallow type floats having capabilities of long ranges and long life continues between the Institution and Massachusetts Institute of Technology. The experiment is primarily a study of oceanic circulation. The freely drifting deep probes (SOFAR) will signal both navigational and environmental data by underwater sound to shore based hydrophones. The principal components for 3 floats have been delivered and the construction is essentially completed. It is anticipated that the first will be launched in January 1968.

A general purpose instrument called "Autoprobe" has evolved from earlier work with the special purpose isotherm follower. The Autoprobe is a deep water variable displacement device able to adjust its depth in the ocean

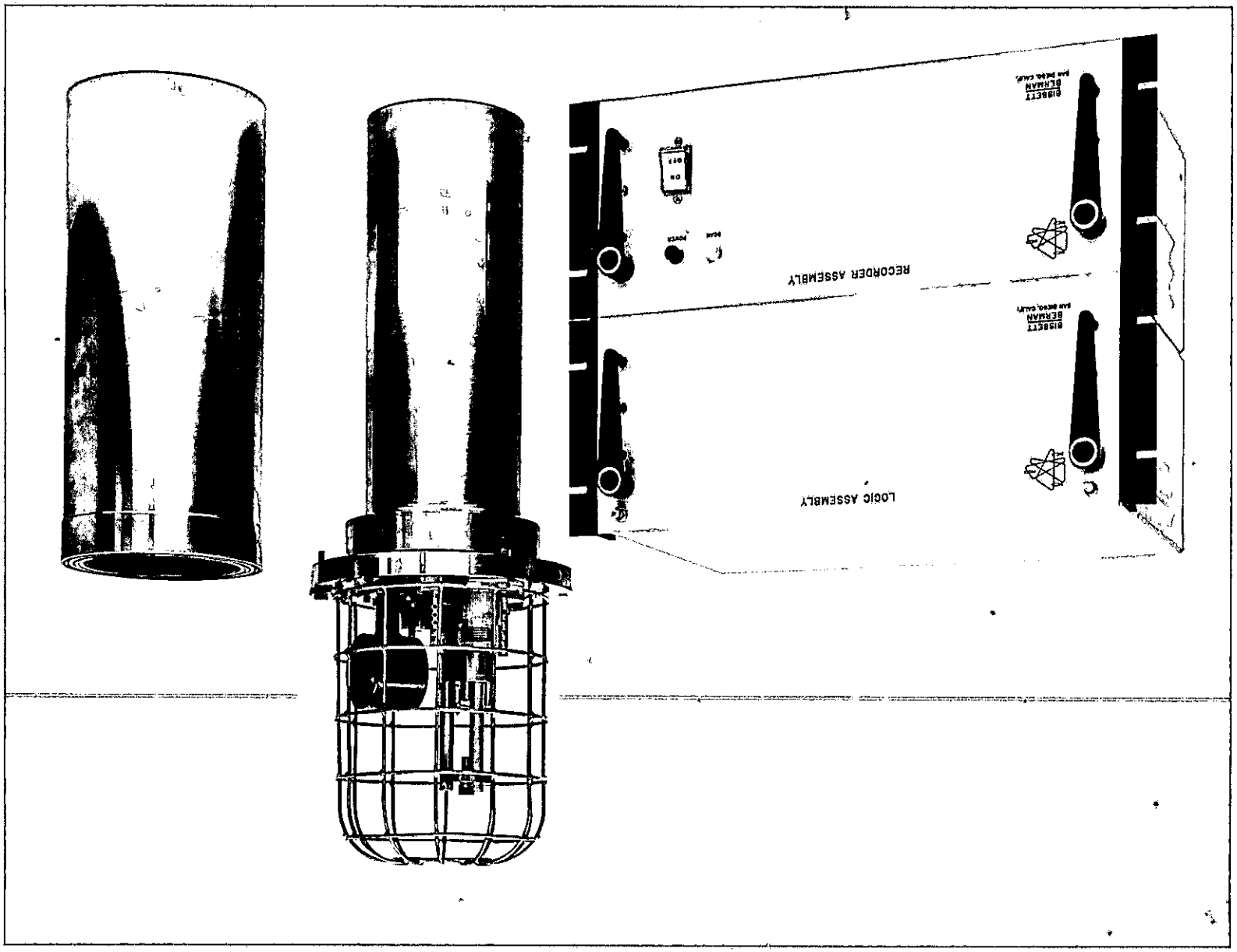

Fig. 1. (Webb-Drever) *Alvin* Ocean Sensor and Data System.

without physical connection to a surface ship. The instrument can be operated in isobaric or isothermal mode or make programmed excursions at any depth. As a platform it will carry many types of instrumentation with the capability for both internal recording and/or sonic data telemetry. The instrument is intended to carry out observations of internal waves, tides, and oceanic microstructure which would be difficult or impossible by any other means.

The Autoprobe has been tested during 15 shallow water tests, and has proven operational. This work will continue into 1968, anticipating several shallow water tests to study the dynamics of the instrument, and the control system stability. Modifications and improvements will be incorporated as a result of these tests. The Autoprobe will be field tested in three deep water trials in 1968. This work is being carried out by Kenneth H. Burt and in collaboration with Prof. Alden Winn of the University of New Hampshire.

The development of bottom marker beacons for use with moored ocean stations has been completed. About 50 of these beacons have been used quite successfully, by the Buoy group at Woods Hole in the field and will in the future be furnished to our specifications by a commercial supplier. Three (3) new prototype designs of special purpose beacons have been evolved this year. In each case the field trials have been successful and a request for the construction of about 15 more have been received.

Work continued in several areas of experimentation aimed at making improvements in a broad range of instruments, particularly the testing and evaluation of chemical and electro chemical power sources and the development of electronic circuit for use without protection from the hydrostatic pressure of the ocean.

INFORMATION PROCESSING CENTER

Melvin A. Rosenfeld

During the year 1967 the physical make-up of the Information Processing Center's equipment has changed little. Two keypunches and one verifier have been added; one 026 key-punch to service our users and an 029 key-punch and 059 verifier to eventually replace existing equipment. These are the first of the new machines which will be installed early in 1968 as part of our changeover to a new computer system. These machines are currently in use on programs and data which will be processed on the new system.

Total computer usage in 1967 was approximately 2089 hours, of which approximately 1851 hours were chargeable to Institution contracts or outside customers. This is a 5 percent increase over chargeable hours in 1966. While this increase is not as great as the previous two-year period, it is worth noting that the monthly use time was distributed much more evenly this past year. As a way of life the Information Processing Center experiences a vast increase in computer usage during the summer months because of the influx of summer people at the Institution. The usage in 1967 has shown less fluctuation than in 1966 and has been brought about mainly because more programs are in the operational stage than last year. This more even work load results in two advantages: (1) More effective use of the computer facilities which allows a meaningful evaluation of month-to-month and year-to-year facility changes and additions. (2) More reliable results because a better organization can be built when people and equipment are used to their fullest extent.

The result is better service to computer customers and, in turn, a continuing increase in computer usage and effectiveness.

The computer use among our major contract and grant areas was (to the nearest whole percent):

Office of Naval Research	65%
National Science Foundation	17%
Geological Survey	5%
Atomic Energy Commission	4%
Other	9%
	100%

As in 1966 the major user of the computer is still the moored buoy project. The many observations taken by moored instruments each month are collected and analyzed. Many of the new program developments started last year are currently operational and in daily use. New program developments are being augmented, such as using digital filtering techniques and fast Fourier transform techniques of spectral analysis to vastly increase processing efficiency.

There has been a substantial increase in business applications on the computer during 1967. Payroll distribution, telephone analysis and stockroom reconciliation are now processed monthly. A continuing effort is being made to include other areas and make a more detailed analysis of business applications in the future.

The staff of the Information Processing Center at years' end consists of 14 people working full time and 3 part time. During the year, a computer operations supervisor, one analyst, and one programmer were added to the staff. Minor changes in the operating and keypunch personnel were made.

In the area of education two classes were held during the year on the basic FORTRAN language to aid non-programmers in acquiring the skill necessary to effectively use the computer. These classes were mainly attended by summer students, but some year-round institution scientists also took advantage of the classes. There were approximately fifteen people attending each session. There was also one class given to advanced programmers to help them make the transition between the FORTRAN II language of the GE 225 to the FORTRAN IV language used by the new computer. There were approximately 25 in the class, all of which were year-round Institution employees. A course in basic statistical methods was given to personnel from the Institution and from the Marine Biological Laboratory. Under the auspices of the Center, a course in multivariate analysis was given by a member of the Department of Chemistry.

Final arrangements were completed in mid-year to acquire a new computer in 1968. Scientific Data Systems SIGMA 7 was selected and is scheduled to be delivered in mid-March 1968. A considerable amount of preparatory work has been done by the Center staff during the last few months to make this transition as smooth as possible. Classes have been attended by all members of the staff and new and revised programs and procedures are in the process of being written. The new computer will be housed in a building being remodelled for its specific use. The work of laying out the new installation has been completed and construction has begun at the site.

The SIGMA 7 computer is the most current of the third generation computers available today. Its capacity and internal speeds are far greater than the GE 225 and will serve the needs of the Institution's scientific and business areas for some time. In addition to its normal computing ability, its real-time capacity will enhance its value to the Institution.

The equipment as it will be initially installed consists of:

SIGMA 7

Memory	32,000 words
Two Discs	3 million bytes each
Three 9-channel Magnetic Tape Drives	
One 7-channel Magnetic Tape Drive	
Paper Tape Reader and Punch	300 CPS
Card Reader	1500 CPM
Card Punch	300 CPM
Line Printer	1000 LPM

Provisions are also being made for a CALCOMP Plotter to be used off-line. Consideration has also been given to the addition of an analog to digital converter and expanded memory in the near future.

In summary, 1967 was a very eventful year for the Information Processing Center. Our ability to service the scientific needs of the Institution has been established by the increased amount of operational processing now done. The expansion of these services into the business areas has begun to show results. And finally the future growth of this ability has been assured by the decision to acquire a new third generation computer.

VLF/OMEGA NAVIGATION

J. Stanbrough

The objectives of this study of very low frequency (VLF) electromagnetic techniques has been to (1) assess the long-range capabilities of VLF/Omega, (2) provide relative navigation for on-station drift measurements, and (3) determine VLF inputs for satellite navigation--ship speed and course during the doppler measurement of the satellite.

The equipment on *Atlantis II* consists of a three-receiver VLF navigation and timing system in which the reference is an oscillator that has a stability of approximately one part in 10^{11}. A clock with numeric readout is part of the system. This equipment is very useful in making determinations of the speed and course made. A two-receiver VLF/Omega set has been assembled for further experiments in navigation including direct plotting, speed and course made, and Omega navigation. The latter system has electronic servos which permit faster sampling and is appropriate for use in medium speed aircraft as well as on ship. An Omega commutator permits the use of Omega stations for range-range data, if desired. It is possible, but difficult, to use Omega in the hyperbolic mode with the two-receiver system.

Charting data for the North and South Atlantic, the Mediterranean, and the Baltic has been completed in a format (similar in some ways to HO214) which gives the travel time in microseconds from the VLF stations and the intersected latitudes and longitudes. Also available for relative on-station measurements are computations of range and bearing to VLF stations from each degree of the North and South Atlantic, Mediterranean, Indian Ocean, North Pacific, Caribbean, and the Greenland Sea. These data have been microfilmed and are on small rolls, available to investigators.

VLF/Omega navigation was employed on several cruises of the Institution in 1967. These were the cruises of *Atlantis II* from Buenos Aires, Argentina to Recife, Brazil in March and April and to the Baltic in May and June, and *Crawford* in August during a study of the Gulf Stream. Omega navigation was accomplished by the C54Q aircraft during November and December in the area 61° west to 55° west and 19° north to 14° north.

The cruise of *Atlantis II* in the South Atlantic was northward along the coast of Argentina and Brazil, and many visual sightings were possible for checking the VLF navigation. The prime interest was in determining the ship speed and course made over the ground. Speed was determined to 0.1 knot, and course was indicated to 0.5 degree. Positions were in agreement to within two nautical miles. Generally, the speed and course measurements were made over six-minute intervals.

Professor Paul Mangelsdorf used the two-receiver VLF system on *Crawford,* and he has reported that his results show relative navigation to within one hundred yards. The receivers were read and recorded every five minutes for digital processing ashore.

Differential Omega navigation was used on the C54Q aircraft for ten flights totalling 15,000 nautical miles in mapping the magnetic anomalies of the sea floor. Track spacings of five and ten miles were practical with Omega. Positions were plotted every five minutes, and flight corrections were made to the auto pilot when needed. The lane count and the accuracy of the system were checked at a selected island point at the beginning and end of each flight. The nominal results were within 1.0 nautical mile; exceptions were attributed to improper corrections for diurnal effects. In the period of two months, more than 150 hours of in-flight Omega navigation were achieved in what is believed to be the first extensive use of this system in a research aircraft carrying out oceanographic measurements.

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